VIRGINIA WATER RESOURCES RESEARCH CENTER

PROCEEDINGS

VIRGINIA WATER RESEARCH SYMPOSIUM 2005
BALANCING WATER LAW AND SCIENCE

VirginiaTech

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2005

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PROCEEDINGS

Virginia Water Research Symposium 2005

Balancing Water Law and Science

Editor:

Tamim Younos

October 10-12, 2005
The Virginia Tech Inn and Skelton Conference Center
Virginia Tech
Blacksburg, Virginia

P11-2005

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FOREWORD

The 2005 Virginia Water Research Symposium was held in conjunction with the 40th anniversary of the Virginia Water Resources Research Center. The anniversary events featured keynote speakers that included Dr. Charles Groat (former USGS director and currently Professor at the University of Texas, Austin), Dr. Gerald Galloway (Professor, University of Maryland), Dr. Jan Stevenson (Professor, Michigan State University), and the Honorable Tayloe Murphy, Jr. (Virginia Secretary of Natural Resources). Keynote speakers addressed issues on integration of water science and policy, the national policy agenda, water management issues in Virginia, and ecosystem protection. Keynote addresses were followed by four water science and policy forums that addressed uncertainty in the TMDL program, restoration of the Chesapeake Bay, groundwater management, and water supply and management. The content of the 2005 water research symposium was mostly focused on these forums and follow up discussions. Due to the time limitation, only a few research papers were accepted for presentation and were presented at four concurrent sessions.

The Proceedings of the 2005 Virginia Water Research Symposium documented in this publication contain the keynote address by Secretary Murphy, slide presentations on the uncertainty in the TMDL program and part of the groundwater management forum presentations. The contents of the water supply and management forum has been documented in the November 2005 issue of the Virginia Water Central (www.vwrrc.vt.edu), a publication of the Virginia Water Resources Research Center. Copies of slide presentations on the restoration of the Chesapeake Bay forum were not available for inclusion in the symposium proceedings.

Research articles in the proceedings include papers on stream impairment and management (Howard et al.; Webb et al.; and Villamagna), papers on emerging issues related to protecting drinking water (Lee et al; Loganathan, and Kleczyk et al.), papers on innovative approaches for managing water resources (LaRocque et al; and Mooney). Three papers focused on the role of science in conflict management. Full paper by Meazell and abstracts for two papers (Roberts and Agosto; and Spangler and Birkhohh) are included in the proceedings.

As we face new water management challenges in the coming years, it is expected that this document serve as a valuable reference for debating critical and complex water issues in Virginia and across the United States.

Acknowledgements are due to the symposium speakers for their work documented in this publication.

Tamim Younos, Interim Director
Virginia Water Resources Research Center

ENHANCING VIRGINIA'S ENVIRONMENT AND ECONOMY BY IMPROVING WATER QUALITY

Tayloe Murphy, Jr.
Virginia Secretary of Natural Resources

Featured Presentation at the Virginia Water Research Symposium
October 11, 2005

Thank you for inviting me to be with you today to address some of the most important water quality issues that we face in Virginia, and some might argue, in the United States. But before I begin my remarks, I would like to congratulate the conference organizers. The topics before you—from water-supply planning to Chesapeake Bay water quality, to TMDL development, to resolving water resource conflicts—are at the cutting edge of water issues today. These issues are not going away, and we will continue to need forums like this one to develop and refine solutions and to have the kind of information and exchange that is envisioned here at this conference.

I would also like to extend my thanks and my congratulations to the Virginia Water Center Resources Research Center, here at Virginia Tech, as it celebrates its 40th anniversary year. I applaud the work of the Center over the last 40 years and all that it has contributed to the scientific and public policy arenas.

I know that there are many participants at this Symposium who have a greater technical understanding of the issues than I have; however, I have had a unique opportunity to see these issues from both the legislative and executive branches of our state government. Today, I will talk about some of the experiences I have had during my public career, and about how I see the water programs we have put in place shaping the future quality and quantity of our waters. I will also try to relate our land use and economic policies to water issues.

Let me begin by focusing on the significant initiatives that have been developed during Governor Warner's administration for nutrient and sediment reductions in the Chesapeake Bay. I submit to you that the water-quality management programs we have developed for the Chesapeake Bay and its tidal tributaries, when implemented, will lead to a more sustainable future in both economic and environmental terms.

At this point, I think a bit of history would be appropriate and helpful. Virginia has been a partner in the regional efforts to restore the Chesapeake Bay since the signing of the first Chesapeake Bay Agreement by Governor Robb and his counterparts in 1983. Just as our understanding of the Chesapeake Bay estuary in scientific terms has advanced, the policy response, as embodied in the various Chesapeake Bay Agreements, has advanced as well. In 1987, Governor Baliles led the effort to add greater specificity and measurable goals to the second agreement among Maryland, Pennsylvania, Virginia, the District of Columbia, the U.S. Environmental Protection Agency, and the Chesapeake Bay Commission. Finally, in the year 2000, a third agreement was signed by Governor Gilmore and his counterparts that, even with its faults, is still considered a model for ecosystem management worldwide.

In my opinion, the centerpiece of the "Chesapeake 2000" agreement is the commitment to improve water quality sufficient to remove the Chesapeake Bay and its tidal tributaries from the EPA list of impaired waters. In less bureaucratic terms, it means that we are committed to make the waters of the bay healthy enough for the survival of plants and animals that inhabit them.

Clearly, this is an ambitious task. Some would even argue that it is unachievable, especially in the timeframe envisioned in 2000. Despite the fact that this task may take longer than originally planned, the efforts we have made in the past and those that are currently underway have not been a waste of time. In many respects, the reductions we have made so far have allowed us to hold the line against further degradation in the face of a fast-growing population. We have certainly made progress through the efforts of farmers, local governments, sewage treatment plant operators, industries, developers, and many others who, through incentives or by regulation, have installed and maintained nutrient- and sediment-reduction practices.

Now, however, we must dramatically reduce the flow of nitrogen, phosphorus, and sediments into the Bay and its tributaries in order to achieve healthy waters. We know that we cannot improve conditions in the Bay and its tidal tributaries unless we cap annual nitrogen and phosphorous loadings throughout the watershed at 175 million pounds and 12.8 million pounds, respectively. In order to accomplish this, we must control nutrient pollution from all sources. We must change the way we farm, the way we develop land, the way we treat wastewater, the way we use septic tanks, the way we manage storm water, and the way we control air pollution. These changes will call for significant action by everyone.

Unless we take action to address each of these sources, we must be prepared to tell the citizens of Virginia, and of this region, that they are unlikely to see any meaningful, permanent improvement in the health of the Bay and its tributaries.

Since the adoption of nutrient cap limits by the Chesapeake Bay partners, there has been a good deal of discussion with respect to the cost of implementing the tributary strategies that have been developed by the partners, which now includes Delaware, New York, and West Virginia in addition to Maryland, Pennsylvania, Virginia, and the District of Columbia. If the states, the federal government, and the localities fail to make substantial financial contributions to meet our goals to conserve our natural resources, the cost will be imposed on someone else. As I have frequently said: there is no such thing as a free lunch. Environmental degradation always places a cost on someone, and usually not the individual causing the damage. A waterman, or a seafood processor, or some other business person who depends on water quality will tell you they have picked up the tab over and over again.

We, as a society, have apparently decided that the best policy is to pass the buck to those least able to afford it. In a book published last year entitled *Hope's Horizon: Three Visions for Healing the American Land*, the following statement was attributed to former United States Senator Gaylord Nelson of Wisconsin: "The economy is a wholly owned subsidiary of the environment." We must continue to make the point that the health of our economy depends in large measure upon the health of our natural resources. A degraded environment will almost certainly promote economic disaster. I have always made the case that the foundation of our quality of life, and indeed our economic prosperity, is based on our natural resources.

It has always troubled me when I hear someone talk about economic development in Virginia only in terms of the amount of concrete poured or the number of new factories that have opened. When they speak about job losses, they tend to dwell only on the number of large businesses that have moved off-shore or closed their doors here in the Commonwealth. They never seem to take notice of the incremental losses in employment resulting from dwindling natural resources. Many of you know that I am from the Northern Neck of Virginia, the peninsula bounded by the Potomac River, the Rappahannock River, and the Chesapeake Bay. When I am at home, it deeply saddens me to ride by one abandoned oyster shucking house after another – by lifeless crab picking facilities that today stand empty – all monuments to a once thriving commercial seafood industry that no longer exists because we placed on that industry the cost of our failure to keep its workplace clean and healthy. The economic losses experienced in areas like the Northern Neck can be seen there every morning, simply by observing the number of sons and daughters of watermen who now commute to Northern Virginia and other urbanized communities to find work. They make these daily trips, *not* as a matter of choice, but as a matter of necessity. They no longer have the option of working productive waters in their own backyards.

When the Chesapeake Bay was placed on EPA's impaired waters list in 1999, we entered a new era in the regulation and management of nutrients and sediments. The goals we are obliged to achieve establish the maximum amount of nitrogen, phosphorus, and sediment that can enter the Chesapeake Bay and its tidal tributaries from all sources and still meet water quality standards. Once reductions from current levels are made, we will need to operate under these levels, or caps, in the face of an ever-increasing population, additional treatment plant flows, and a changing landscape.

I believe we have responded to this challenge, and over the last three years we have built the foundation for reducing nutrients in Virginia and capping them over time. In concert with the General Assembly, we have pursued an aggressive regulatory program, legislative actions, and budgetary support that put Virginia at the forefront in this region and nationwide.

We began by setting nutrient and sediment loading allocations for each of our Bay tributary rivers, and then developing tributary strategies that define the management actions necessary to achieve the reductions. We have revised our tidal water-quality standards to reflect the direct needs of living resources. Dissolved oxygen standards in our tidal waters, for example, are keyed to the needs of fish and shellfish in the various "zones" of the bay, from nursery and spawning areas to deep-water habitat. Increased abundance of submerged aquatic vegetation now constitutes the standard for water clarity. We now have in place a narrative chlorophyll standard for all our tidal waters; however, we expect to adopt a numeric chlorophyll standard for the James River before the end of the year.

We have also constructed the regulatory framework necessary to address nutrient reduction from point sources by adopting technology-based regulations and assigning specific loading allocations to each of our significant municipal or industrial facilities. The programs we have pursued in Virginia recognize the new reality that we must learn to live under nutrient caps. As I have said: To meet our obligations under the Chesapeake 2000 Agreement means that new and expanded nutrient- and sediment-reduction efforts are necessary. It also means that the measures we put in place now, as well as in the future, must be operated and maintained so that we can achieve our reduction goals, and thereafter, remain under our cap loads over the long term. Moreover, I would argue that living under a loading cap will drive innovation and new technology. Smart entrepreneurs, business owners, and public servants will find ways to maximize nutrient reduction in order to meet and maintain our goals, and there will be significant economic value associated with those reductions. I firmly believe that technologies that reduce nutrients beyond what is now possible will be in exceedingly great demand, and I suspect that there are a number of individuals here at Virginia Tech with the ability to meet this demand for improved technology.

At the last session of the General Assembly, a nutrient-credit exchange program was created that will place an economic value on the pounds of nutrients that make up the loading allocations assigned to each significant discharger. Thus, market forces will be brought to bear on nutrient reduction, and assist in achieving our goals.

I am confident that point-source permittees will beat a path to the first engineering firm, or wastewater facility, that develops a technology that reduces nitrogen concentrations in wastewater to a milligram per liter, or less, and it can be hoped that wealth will be created by virtue of such technological innovation.
Even without advances in technology, the simple fact that there are hundreds of sewage treatment plants in this region that will—over the course of the next decade or so—require upgrades means there will be plenty of work for engineers and contractors trained to perform this work.

Likewise, the millions of acres of agricultural and urban lands that will need the installation of management practices, or the retrofit of existing infrastructure, will generate environmental benefit and new economic activity.

Certainly, the environmental benefits of improved water quality are obvious. Reduced nutrient and sediment inputs will lead to improved oxygen levels and water clarity and a reduced amount of algae, all of which will lead to the restoration of aquatic habitat that has been severely compromised. In simple terms, crabs and fish will be able to breath in the Chesapeake Bay and aquatic plants will be able to grow. We should see more abundant fisheries. In addition, we will see the restoration of aquatic populations whose place in the web of life, and the food chain, is irreplaceable.

Our current efforts of restoration are driven, in part, by the economic benefits that will come from restored fisheries in both the commercial and recreational sectors, especially from tourism, and more specifically, the fastest growing segment of the tourism market—eco-tourism. There will also be significant economic activity associated with the industries that support these industries, from the marine trades to sellers of equipment to transportation—and the list goes on.

In addition to the economic benefits that will accrue from restored waters, the intangibles of an improved quality of life and a healthier population will flow from improved water quality. I do not know how to place a dollar value on the wonder of the natural environment that can be seen in the eyes of a child who catches his first crab, or in the decisions a business owner makes about the happiness of his employees by locating in an attractive place. I do believe, however, that in some sense these things do have value, perhaps not the value that an accountant can measure, but value nonetheless.

The future I see goes well beyond the installation of best management practices on farms and developed areas, and the upgrades to sewage treatment plants. In my view, there are broad implications for how we grow and develop as a society and the value we place on our landscapes, and how the landscape sustains us in the future.

In simple terms, I believe a nutrient cap will be the impetus for changes in the way we value the use of land. First, I see the potential for more robust agriculture and forestry in Virginia. Under the framework of the nutrient-credit trading program, when wastewater-treatment facilities expand beyond their current capacity or build new plants, they will be required to offset any additional nutrient load from those facilities by installing (or overseeing the installation of) best management practices on land to capture nutrients that would otherwise run off into adjoining waters.

This will mean that farm and forest land will take on value as a location for nutrient reductions. Farmers should benefit from a new stream of income arising out of the installation and maintenance of best management practices on their property under contacts with the owners of wastewater treatment plants. I can also see where a municipality might purchase an easement on a farm or forestland to ensure that they have lands available for the installation of nutrient- and sediment-reduction practices in order to accommodate growth in the future.

I anticipate that we will better integrate our land use planning with our water-quality obligations. Local governments, as they deal with meeting nutrient caps, will need to do a better job in aligning their need for sewage treatment, and the nutrient impacts of growth, with the decisions they make about development and conservation of land. I can see a future where conservation of land has equal footing with so-called economic development. The value associated with preserved lands, in this nutrient-based economy, may rival those of developed lands.

I foresee a time when we will place a significant value on what are termed the "ecological services" that trees, wetlands, and pastures provide. At a conference in St. Louis sponsored by the White House Council on Environmental Quality in August [2005], United States Secretary of Agriculture Michael Johanns announced that USDA will be creating programs that will allow farmers to accumulate what he called "ecological credits" that could provide a cash flow in exchange for conservation practices. Although Secretary Johanns may have had in mind international pressure on the U.S. to reduce the amount paid to farmers in the form of crop subsidies, I hope that we are thinking along the same lines. Conservation, whether driven by the World Trade Organization or by nutrient caps in the Chesapeake Bay watershed, can be a source of cash in the pockets of farmers and the owners of forestland in this region.

In some measure, I think that with these nutrient caps we will stop passing the buck and feasting on a free lunch actually paid for by someone who should not bear that responsibility. The conservation of our natural resources will become more integral to our economic future and in many ways the true cost of nutrient reduction will be borne by those who generate those excess nutrients.

Even though I may sound optimistic about the future, I would not suggest that it will be easy. We have significant challenges facing us particularly in the reduction and control of *nonpoint* nutrient pollution. As you know, they come from everywhere: from farm fields and suburban lawns, from septic tanks and rooftops, and from the air. The management framework for nonpoint sources is quite different from the permitting systems we have available for point sources. I hope that conferences such as this will help address this great challenge.

Before I conclude, I hope you will allow me to offer some observations about our efforts to restore the Chesapeake Bay, and some of the realities we face in realizing the future that I have outlined and that I hope will be realized. I am certain, regardless of the outcome of this year's gubernatorial election, as well as future elections, that Virginia will continue to be an active partner in the Chesapeake Bay Program. We fully understand our geographical place in the Chesapeake Bay region. We are downstream from our partner jurisdictions and it is certain that we will not meet our water quality goals absent concerted action by our upstream friends. We are grateful for their efforts, but we are also cognizant of our own responsibilities to restore water quality in our own rivers whether or not they affect water quality in the main stem of the Bay.

I know that the path we are on will continue to be difficult because, on a statewide basis, support for Chesapeake Bay restoration efforts can wane. Lately I have been disturbed by some self-appointed pundits who have been loud in their criticism of the Chesapeake Bay Program, and its inability to solve all the Bay's problems all at once.

Apparently, they have apparently just discovered that politics shape governmental responses to the Bay's problems. I do not mean politics in a partisan sense; I mean politics as it is practiced in the decisions that are made by the executive and legislative branches. The simple fact is that natural resource managers are, and always have been, in direct competition with healthcare, public safety, education, transportation, and all the other so-called "core" functions of government for the resources necessary to achieve our goals. The allocation of those resources is a political process. As much as those of us who are given the responsibility of protecting our natural resources would like, we cannot simply wave a wand to garner the necessary political and financial support for our priorities. We cannot do it alone. Legislative and executive branch leaders must be convinced that their constituents, colleagues, neighbors, and friends are willing to take the actions necessary to achieve the ambitious goals before us.

The simple fact is that political leadership will be necessary to sustain any permanent change to the way we protect our natural resources in Virginia. Simple legislative or regulatory actions, such as allowing significant deviations from the nutrient caps we are establishing, will nullify the environmental and economic future I have described. I solicit your support to keep this from happening.

WATER SCIENCE AND POLICY

FORUM PRESENTATIONS

Some Thoughts on Uncertainty and TMDLs

K.H. Reckhow
Nicholas School of the Environment & Earth Sciences
Duke University

ASSESSING THE TMDL APPROACH TO WATER QUALITY MANAGEMENT

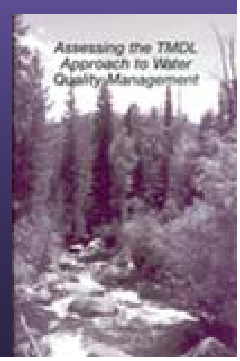
Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction

Water Science and Technology Board
Division on Earth and Life Studies

National Research Council

National Academy Press
Washington, D.C.

2001



Key Recommendations – Overall Program

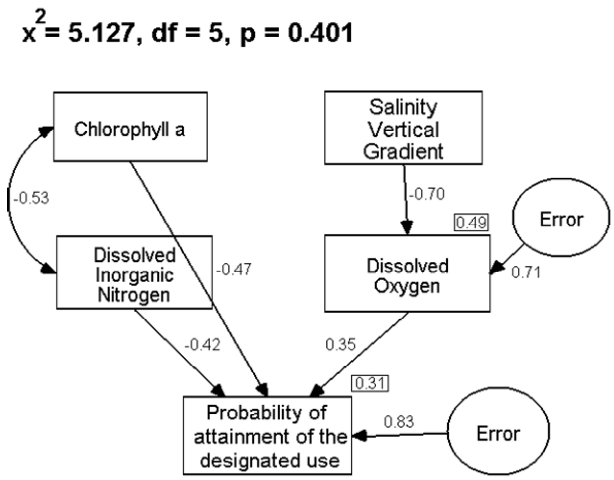
• The TMDL program should focus first and foremost on improving the condition of waterbodies as measured by attainment of designated uses.

• Scientific uncertainty is a reality within all water quality programs, including the TMDL program, that cannot be entirely eliminated.

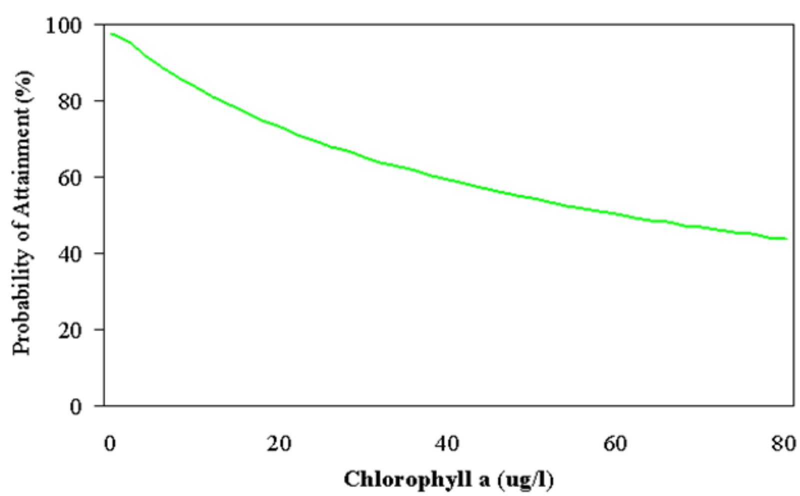
Key Recommendations – Standards & Violations

•The criterion used to measure whether a waterbody is meeting its designated use can be positioned at different points along the causal chain connecting stressors (such as land use activities) to biological responses in a waterbody.

Structural Equation Model: Neuse River Estuary



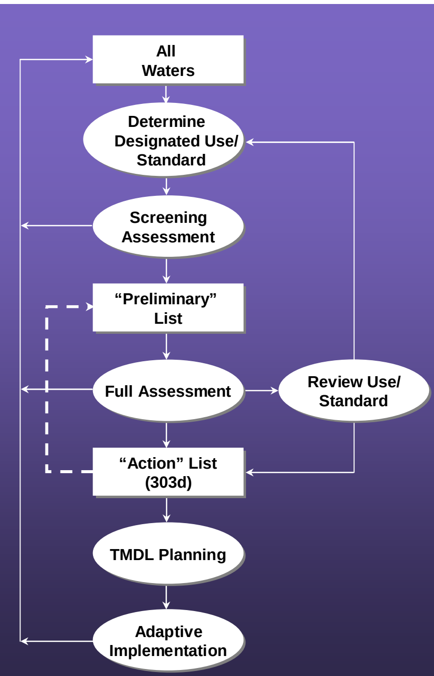
Neuse – P(Use Attainment) vs. Chla



Key Recommendations – Standards & Violations

- As the basis for determining water quality standard violations, EPA should approve the use of both a preliminary list and an action list instead of one 303d list.

- EPA should endorse statistical approaches to proper monitoring design, data analysis, and impairment assessment.

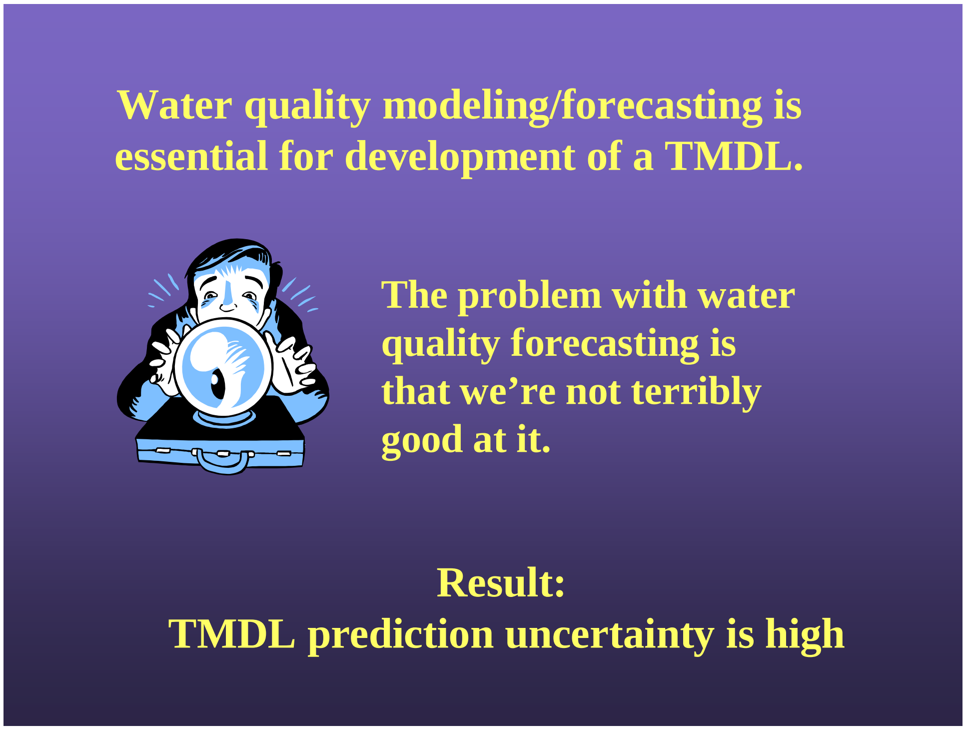


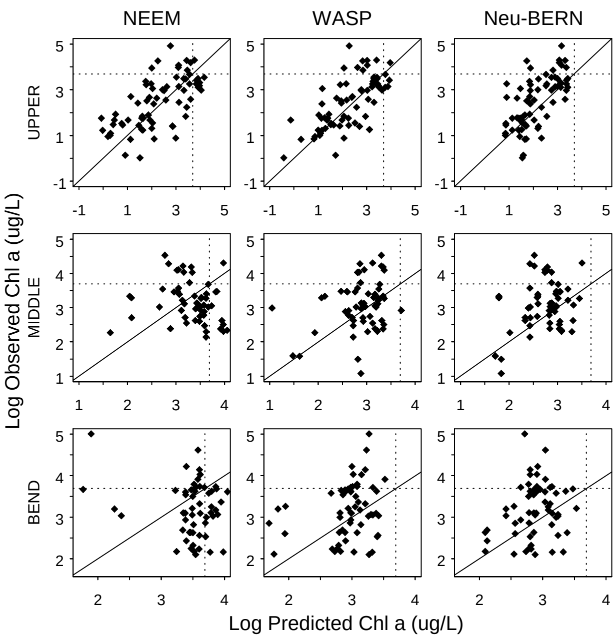
Key Recommendations – Standards & Violations

- As the basis for determining water quality standard violations, EPA should approve the use of both a preliminary list and an action list instead of one 303d list.
- EPA should endorse statistical approaches to proper monitoring design, data analysis, and impairment assessment.
- *Use attainability analysis* (UAA) should be considered for all waterbodies before a TMDL plan is developed.

Six Reasons for a Change in the Designated Use and/or Water Quality Standard as Determined by UAA (EPA, 1994)

1. Naturally occurring pollutant concentrations prevent attainment of the use.
2. Natural, ephemeral, intermittent or low flow or water levels prevent the attainment of the use.
3. Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied.
4. Dams, diversions, or other types of hydrologic modifications preclude the attainment of the use.
5. Physical conditions related to the natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses.
6. Controls more stringent that those required by the CWA mandatory controls would result in substantial and widespread adverse social and economic impact.


Water quality modeling/forecasting is essential for development of a TMDL.
The problem with water quality forecasting is that we're not terribly good at it.
Result:
TMDL prediction uncertainty is high


NEEM
WASP
Neu-BERN
UPPER
MIDDLE
BEND
Log Observed Chl a (ug/L)
Log Predicted Chl a (ug/L)

Yet, we need predictions to guide decision making, so what should we do?

Adaptive Implementation

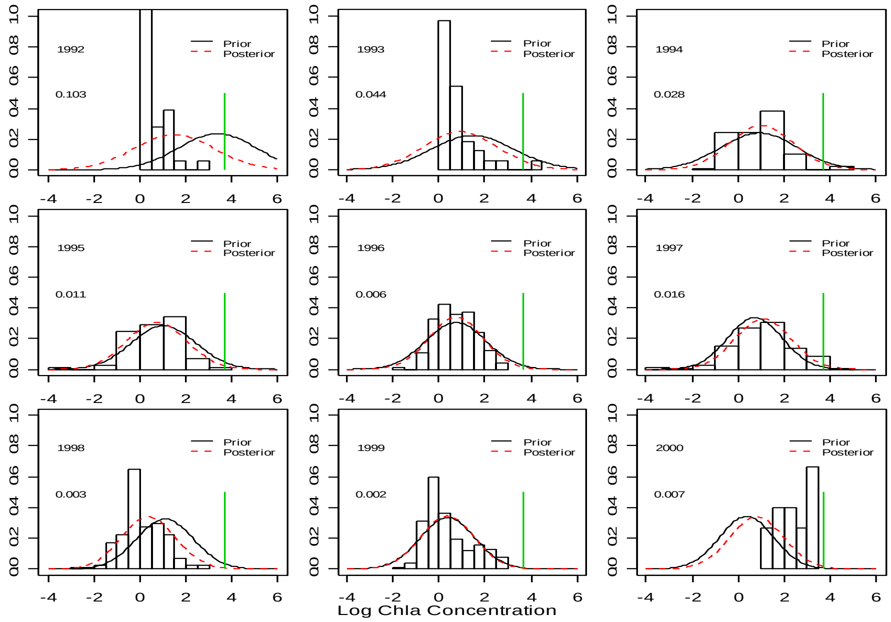
We can "learn while doing;" that is, we can observe how the real system (the actual waterbody) responds, and then use that information to augment the prediction for the modeled system.

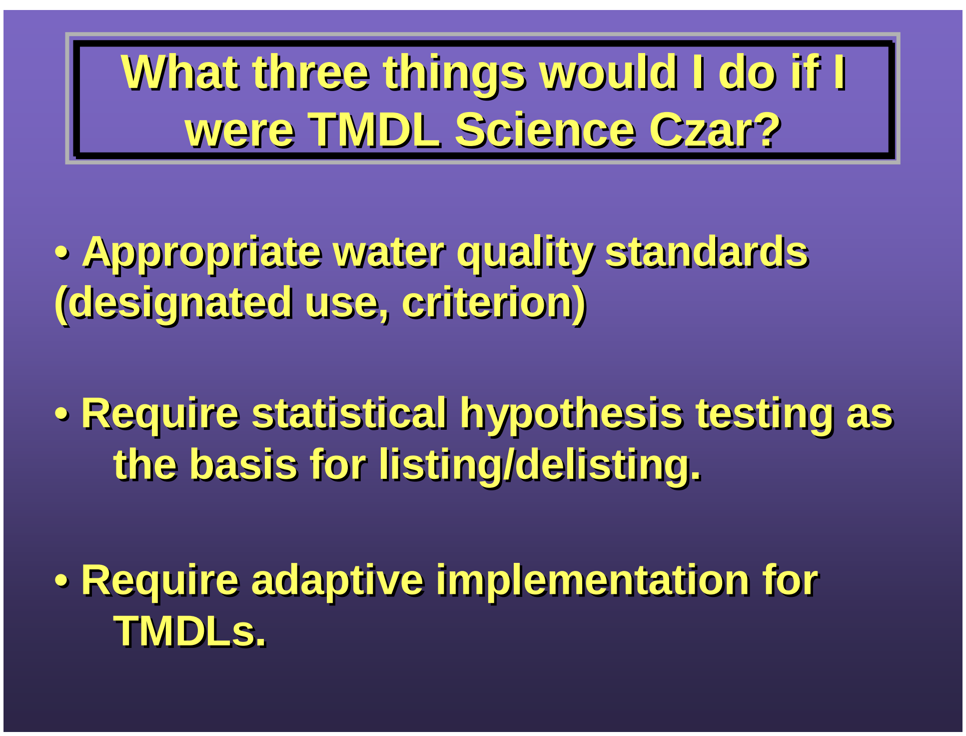
How might we conduct adaptive implementation?

- ***Step 1:*** **To define the TMDL, a water quality model is applied; the forecast from this model provides the initial estimate of how the waterbody will respond to the pollutant load reductions required in the TMDL.**

- ***Step 2:*** **After the TMDL is implemented (i.e., BMPs & point source controls in place), a *properly-designed* monitoring program is established; this program can be focused on assessment of particular pollutant controls and/or on overall waterbody compliance with standards.**

- ***Step 3:*** **The pre-implementation model forecast (from step 1) is combined with the post-implementation monitoring (from step 2); this provides the best overall estimate of TMDL success and provides the basis for any necessary revisions to the TMDL.**


1992
0.103
1993
0.044
1994
0.028
1995
0.011
1996
0.006
1997
0.016
1998
0.003
1999
0.002
2000
0.007
Prior
Posterior
Log Chla Concentration


What three things would I do if I were TMDL Science Czar?
• Appropriate water quality standards (designated use, criterion)
• Require statistical hypothesis testing as the basis for listing/delisting.
• Require adaptive implementation for TMDLs.

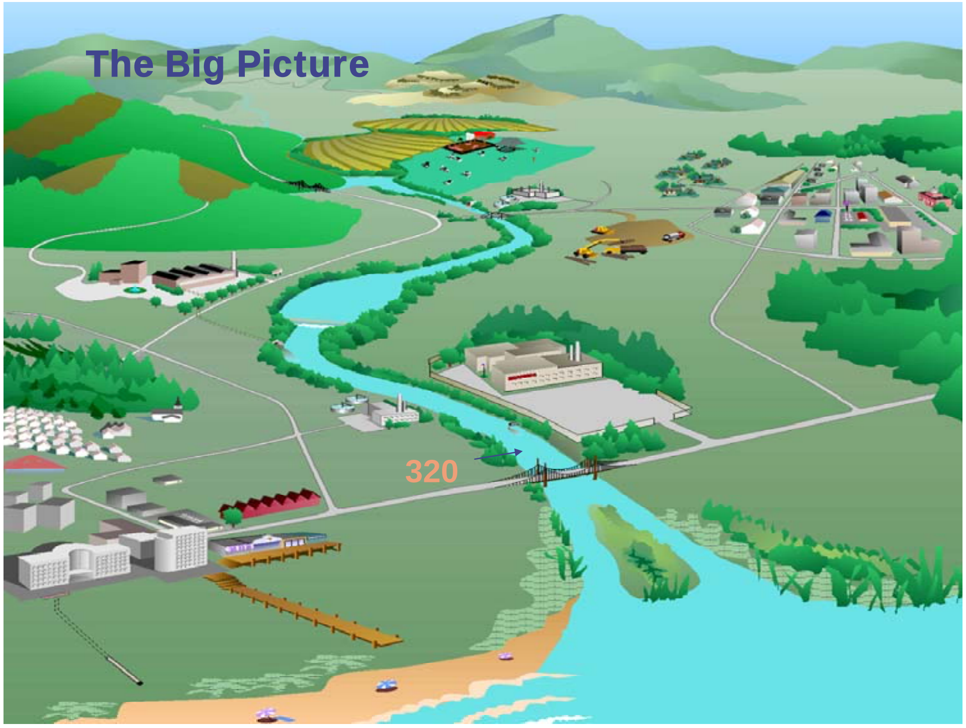
Uncertainty in the TMDL process

Eric P. Smith

Statistics Dept., Virginia Tech

National Water Research Symposium
October 10, 2005

1

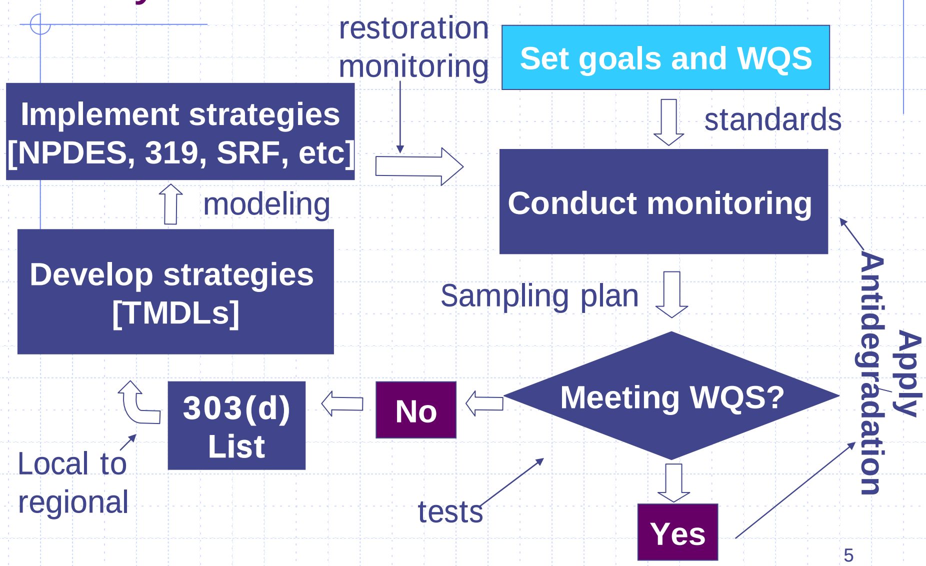


Standards assessment – 303d

- Clean Water Act section 303d mandates states in US to monitor and assess condition of streams
- Site impaired – list site, start TMDL process (Total Max Daily Loading)
- Impaired means site does not meet usability criteria

4

Linkages in 303(d): uncertainty is everywhere



5

Impaired sites

- Site impaired if standards not met
- Standards – defined through numerical criteria
  - Involve **frequency**, duration, magnitude
- –Decision process
  - site listed (or is marginal)
  - site not listed

6

Monitoring uncertainty: Sampling plan

- Fixed stations approach
  - multiple samples over time
  - hard to make statements regarding regional effect
- Probability monitoring
  - single site, single time
  - focus is more regional
  - testing is analogous to outlier testing, hard to detect violation

change of focus from 303 to 305

7

Sampling plan

- Uncertainties
  - how many samples?
  - is probabilistic sampling best for determination of impairment?
  - are there better methods for determining if violations occur?
  - how to connect probabilistic sampling with designated use?

8

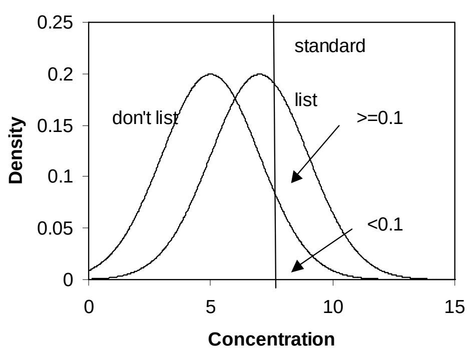
Uncertainty and decisions

- Old method
  - Site impaired if >10% of samples exceed criteria (or 10.5%)
  - Implicit statistical decision process- error rates
  - Does not focus on uncertainty – cutoff is fixed so error rates change with sample size

9

Test of impairment

violation for large values



10

There are better methods

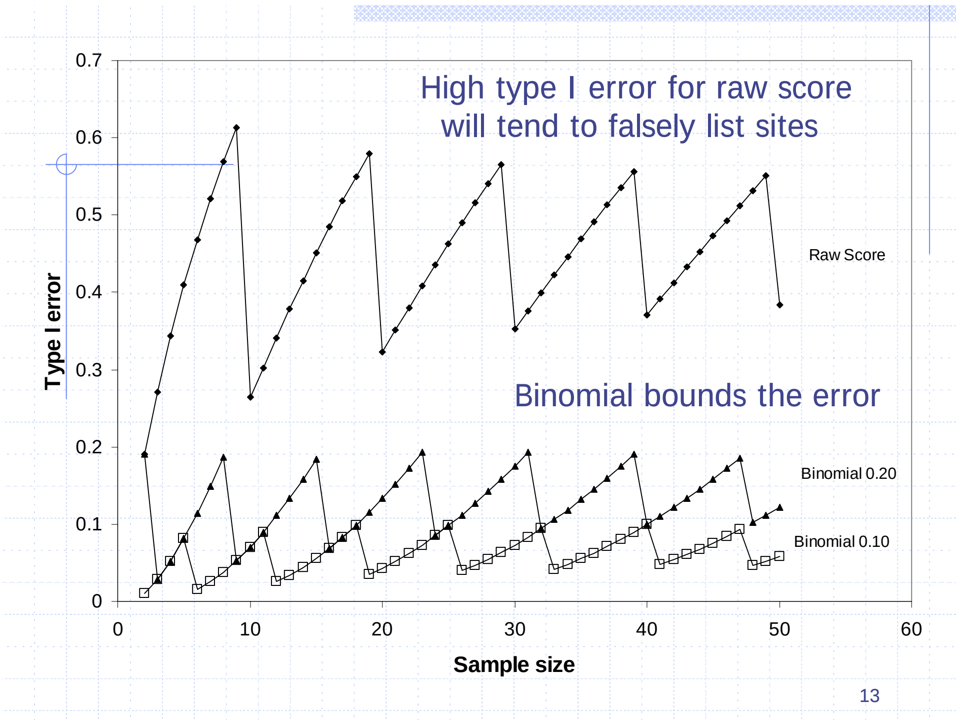
- Frequency:
  - Binomial method
  - Test $p<0.1$
- Magnitude
  - Acceptance sampling by variables
    - Tolerance interval on percentile
    - Test criteria by computing mean for the distribution of measurements and comparing with what is expected given the percentile criteria

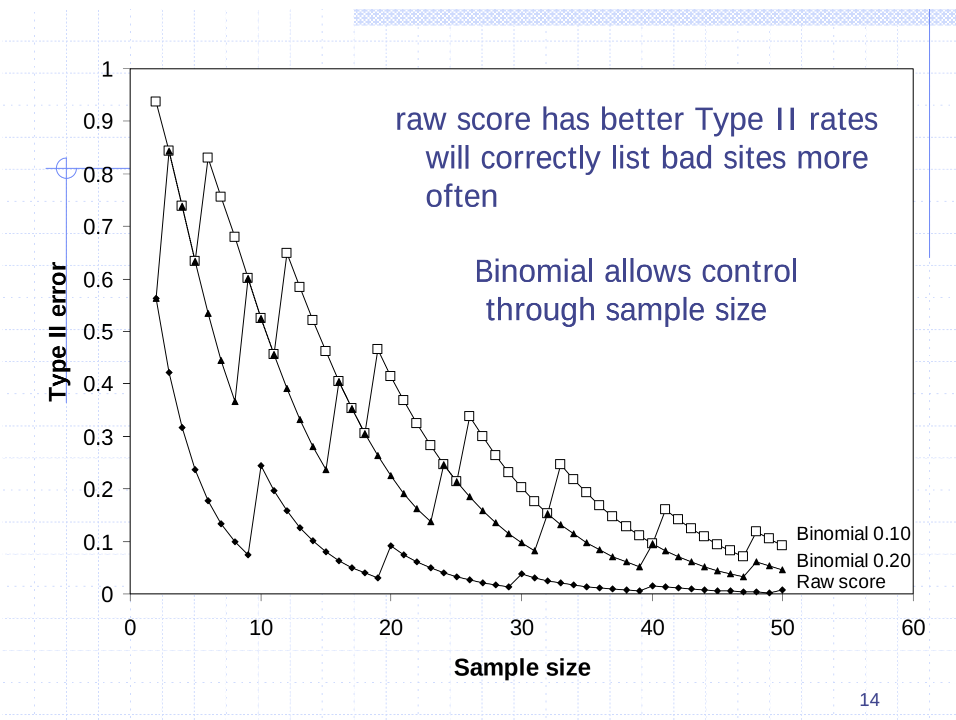
11

Errors and rates

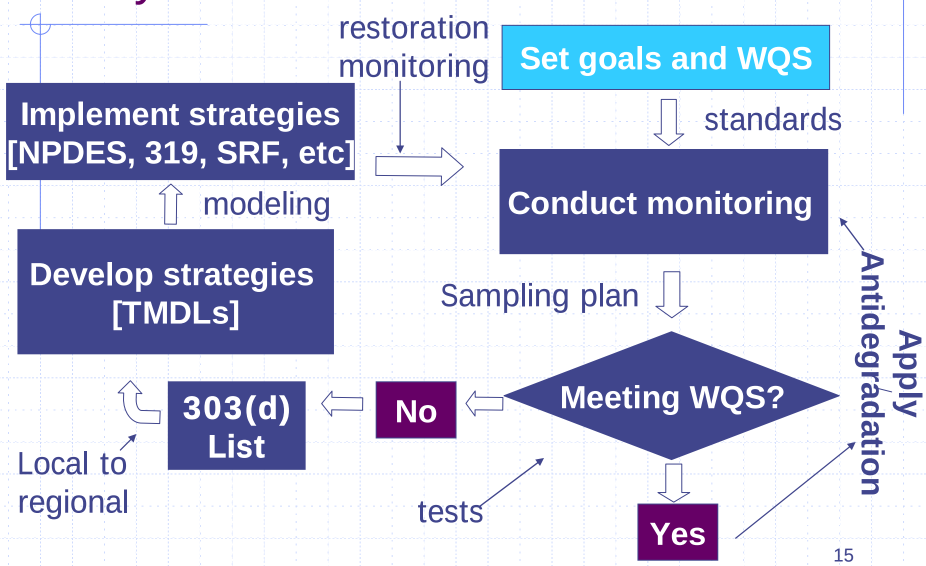
Truth / Decision	No violation	Violation Fail to list
Decide No violation	ok	Type II
Decide Violation =list	Type I	ok

12


High type I error for raw score will tend to falsely list sites
Binomial bounds the error
Raw Score
Binomial 0.20
Binomial 0.10
Type I error
Sample size
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
10
20
30
40
50
60
13


raw score has better Type II rates will correctly list bad sites more often
Binomial allows control through sample size
Binomial 0.10
Binomial 0.20
Raw score
Type II error
Sample size
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
14

Linkages in 303(d): uncertainty is everywhere



15

Missing link

- Approach is local yet TMDL are regional
  - Limited sampling budget; many stations means small sample sizes per station
  - Impairment may occur over a region
  - Modeling must be relatively simple (hard to account for seasonality, temporal effects)
  - Does not complement current approaches to sampling
  - Site history is ignored
  - Not linked to TMDL analysis (regional) and 305 reporting

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Making the assessment regional

Mixed models allows testing overall (regional) impairment as well as local (site specific)

extends to deal with potential problems
time trends, seasonality, correlated errors

Bayesian methods – useful for incorporating historical data or data from other sites into decision
Use likelihood from the previous assessment (D0).
Basic idea: weight new data by prior data

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Comments

- Best not to ignore uncertainty but to include it in the analysis and to try to understand where it comes from
- By including modeling of uncertainty we can often make better decisions.

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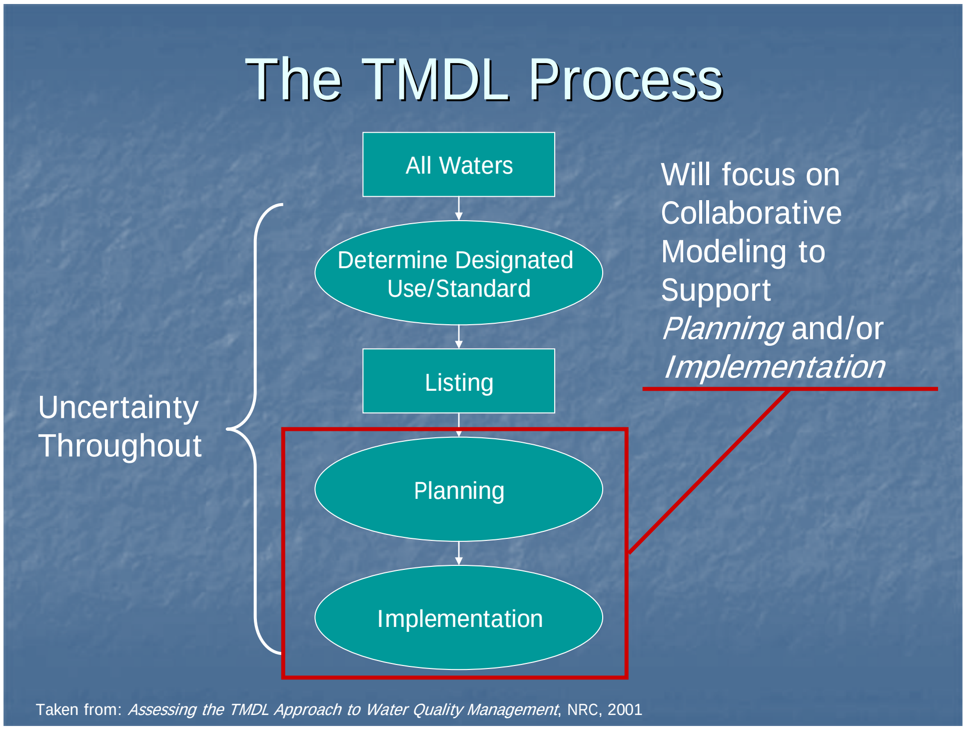
Uncertainty in the TMDL Process: Using Collaborative Modeling to Support Decision-Making

Mark Lorie

National Water Research Symposium

October 10, 2005



As planners, your job is to illuminate the choices.

-Abel Wolman

For uncertainty:

- Illumination involves technical analysis—what is the error rate in predicting the affect of development on phosphorous loadings?
- Illumination also involves values choices—is it acceptable to restrict agricultural practices given the uncertain impact?
- In a multi-stakeholder environment, muddling the two is very unproductive, leading to debates about facts, rather than policy choices.

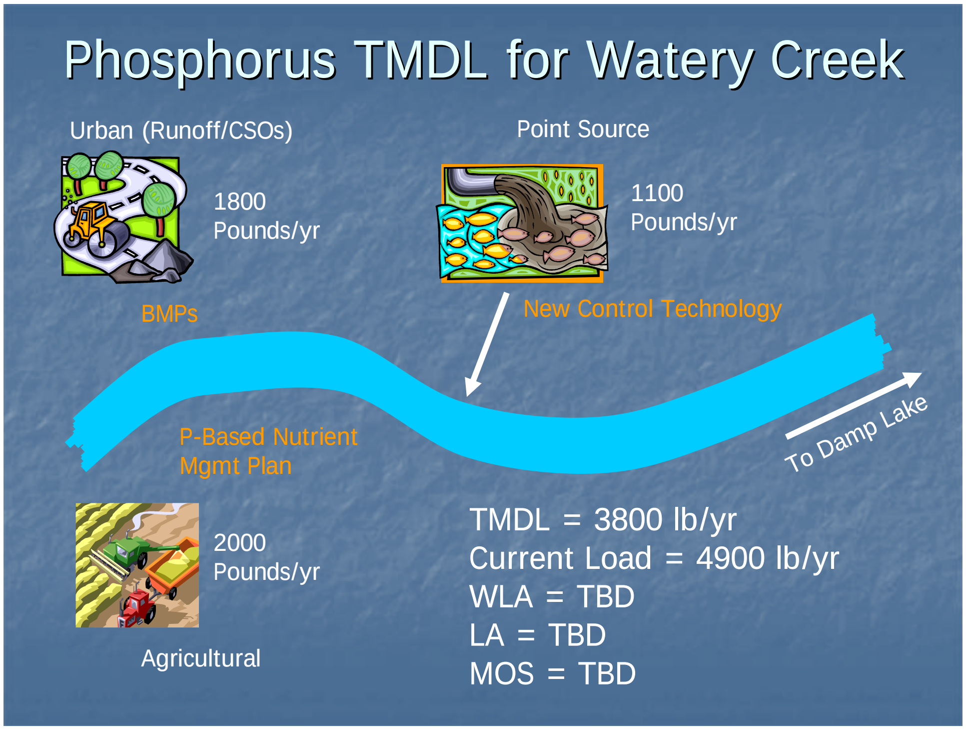
Shared Vision Planning

- Shared Vision Planning integrates traditional planning, systems modeling, and structured collaboration to create a practical forum for making decisions
- The distinguishing feature is the use of a collaboratively built systems model—a Shared Vision Model--to support planning and decision-making
- Goal is to separate factual questions from policy questions to allow for productive debate

Promoting a Shared Vision

Shared Vision Models are:

- Integrated
- Easy to use
- Understandable and transparent
- Relevant to the decision at hand
- Adaptable and flexible to new questions/issues


Phosphorus TMDL for Watery Creek
Urban (Runoff/CSOs)
1800 Pounds/yr
Point Source
1100 Pounds/yr
BMPs
New Control Technology
P-Based Nutrient Mgmt Plan
To Damp Lake
2000 Pounds/yr
Agricultural
TMDL = 3800 lb/yr
Current Load = 4900 lb/yr
WLA = TBD
LA = TBD
MOS = TBD

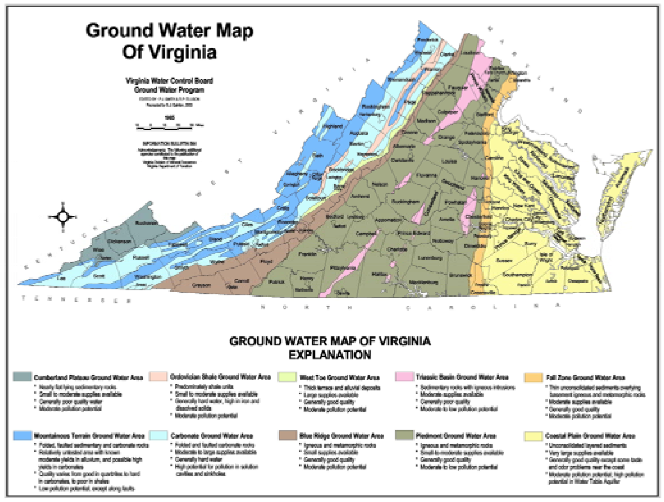

For More Info
IWR's Shared Vision Planning Website:
www.iwr.usace.army.mil/iwr/svp/home.htm
Or just Google "Shared Vision Planning"
Mediated Modeling
by Marjan van den Belt
Modeling the Environment
by Andrew Ford

Virginia Ground Water Management

Application of the ground water withdrawal regulations
within ground water management areas

Robin Patton
Virginia Department of Environmental Quality

Virginia Physiographic Provinces



Virginia Coastal Plain Pre-development

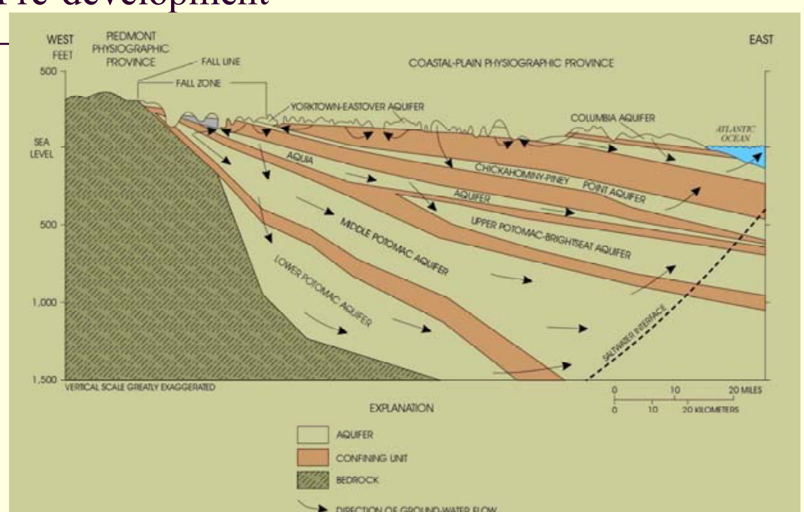
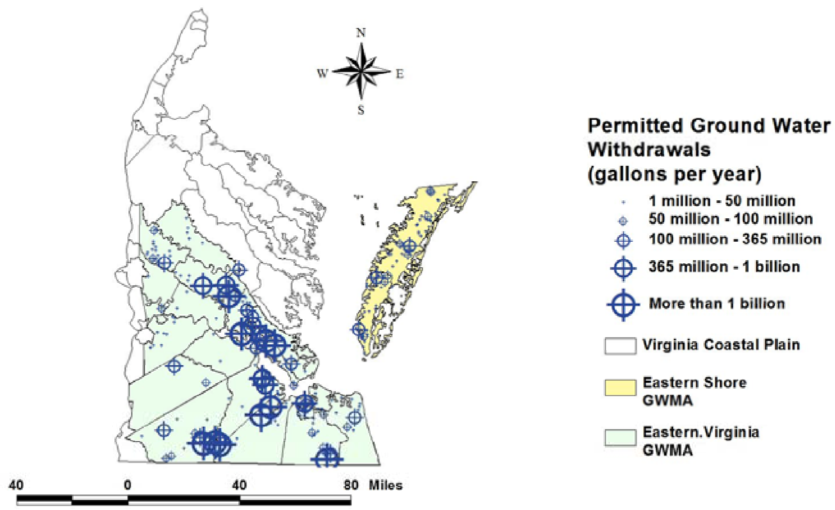
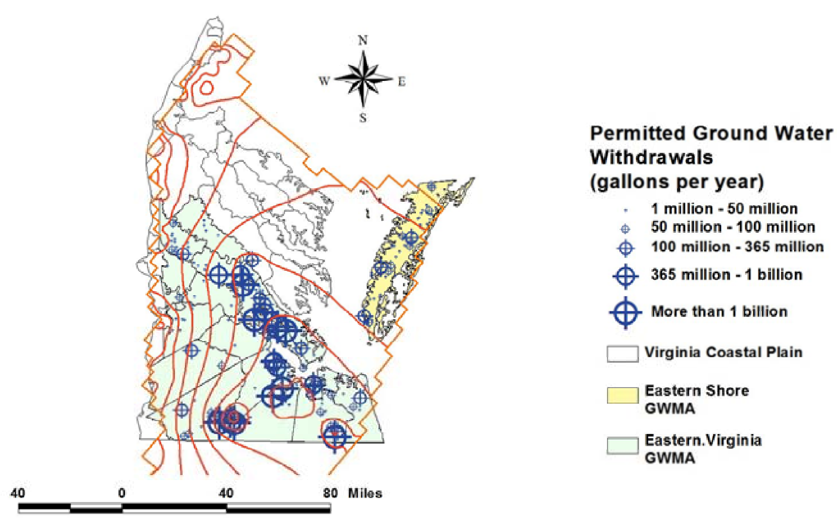


Figure 2. **Generalized hydrogeologic section and direction of ground-water flow in the Coastal Plain Province of Virginia. (Modified from Harsh and Laczniak, 1990.)**

Permitted Facilities - VA Coastal Plain



Permitted Facilities - VA Coastal Plain



Ground Water Management Act
Virginia Code § 62.1-254 et seq.

The General Assembly determines that the right to reasonable control of all ground water resources within the Commonwealth belongs to the public and that in order to conserve, protect and beneficially utilize the ground water and to ensure the public welfare, safety and health, provision for management and control of ground water resources is essential.

Originally enabled in 1973 and applicable in designated Ground Water Management Areas [Eastern Virginia - 9 VAC 25-600-20 et seq. and Eastern Shore - 9 VAC 25-620-10 et seq.]

Revised in 1992 for issuance of permits based on need rather than capacity and to include agriculture as regulated use.

GWMA Regulations 9 VAC 25-610-10 et seq.

Any person or entity wishing to withdraw 300,000 gallons per month or more in a declared management area must obtain a permit.

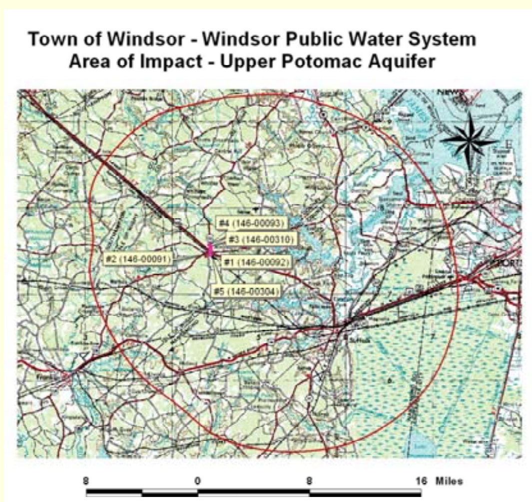
Requirements for Application

- 1. Justification of need for amount of water requested.
- 2. Hydrogeologic information to develop a technical evaluation to determine impacts.
- 3. Mitigation plans for affected pre-existing users.
- 4. Water Conservation and Management Plan:
  - The use of water-saving plumbing and processes.
  - A water loss reduction program.
  - A water use education program.
  - Evaluation of potential water reuse options.
  - Mandatory use reduction during water shortage emergencies.

VA-DEQ Technical Evaluation

- Well construction, geophysics, and water quality are used to determine source aquifer(s) and verify that pump intakes are above aquifer tops.
- Site specific hydrogeologic information is used to develop withdrawal simulations to determine Area of Impact (1-ft drawdown contour from existing total permitted effects) for each impacted aquifer.
- Regulations require reassessment of total impacts for each proposed withdrawal – to insure confined aquifers remain saturated.

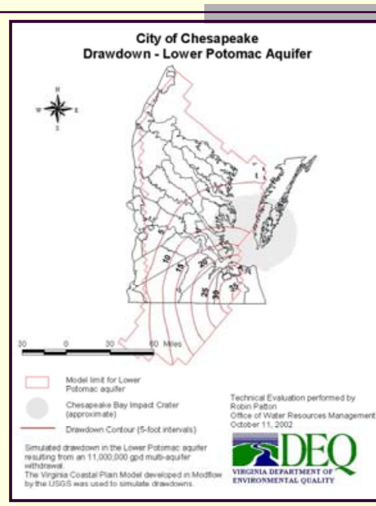
Area Of Impact Example



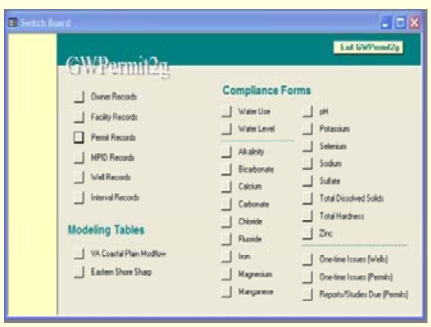
- Mitigation requirements apply to area(s) where one-foot or more of drawdown is predicted to occur as result of proposed withdrawal for any aquifer.
- Permittee has rebuttal assumption of responsibility for negative impacts to existing users within the area.

Regional models are used to evaluate proposed withdrawals for regulatory criteria for permit issuance

- To assess compliance with drawdown criterion
  - Baseline head (Total Permitted Simulation)
- For qualitative analysis of impacts to water quality
  - Reversal of flow
  - Upconing



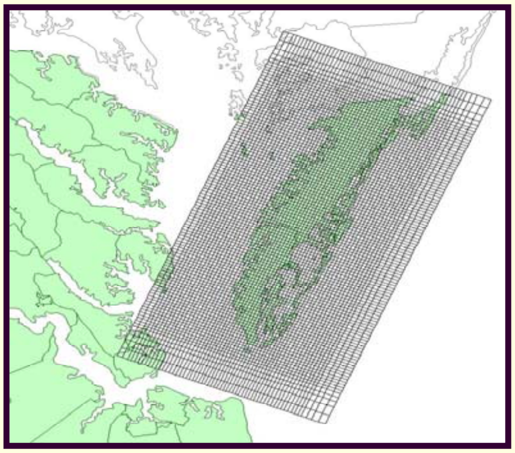
GW Permit
Networked MS Office Database



- Primary regulatory tracking mechanism for applications, permits, and compliance.
- Tracking of well location and construction and withdrawal limits are the basis for regional flow models.

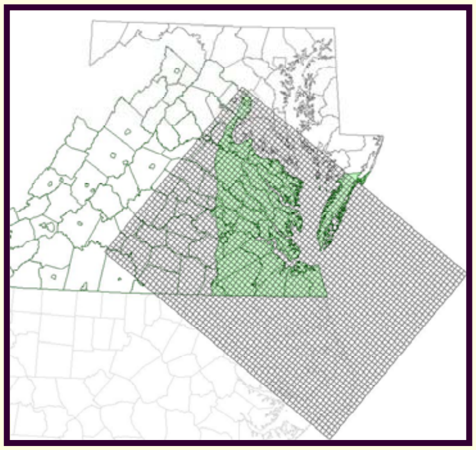
Eastern Shore Sharp Model

- Developed by USGS in late 90’s to look at several pumping scenarios
- Simulates the Yorktown aquifer as 3 confined aquifers
- Simulates salt water boundary as a sharp interface
- Cell side 0.5 miles
- USGS SHARP



Virginia Coastal Plain Model

- Developed by USGS in early 80’s
- Refined and GIS developed in early 90’s
- Simulates 9 confined aquifers + constant head watertable
- Cell sides 3.5 miles
- MODFLOW

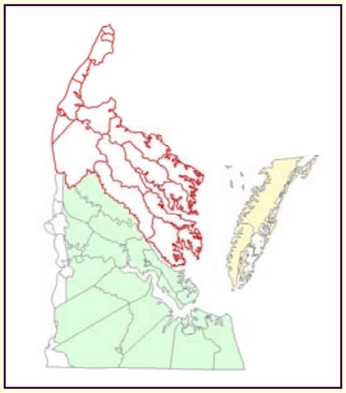


VCPM Annual Simulations

- Water Use
  - Compare to actual water levels
- Total Permitted
  - To develop baseline for regulatory requirement to assess impacts for proposed withdrawals in combination with all existing lawful withdrawals
  - To identify areas where water levels are predicted to fall below drawdown criterion

Issues over time

- unregulated withdrawals
  - domestic use – single home wells in subdivisions
  - coastal plain counties not in GWMA's



Issues over time

- unregulated withdrawals
  - domestic use – single home wells in subdivisions
  - coastal plain counties not in GWMA's
- interstate resource
  - MD
  - NC

Issues over time

- unregulated withdrawals
  - domestic use – single home wells in subdivisions
  - coastal plain counties not in GWMA's
- interstate resource
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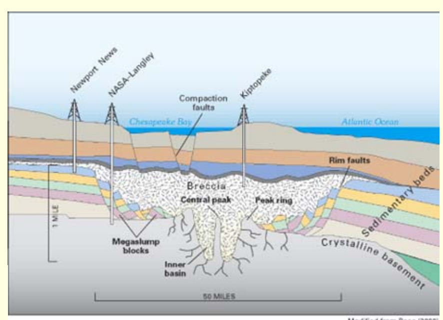
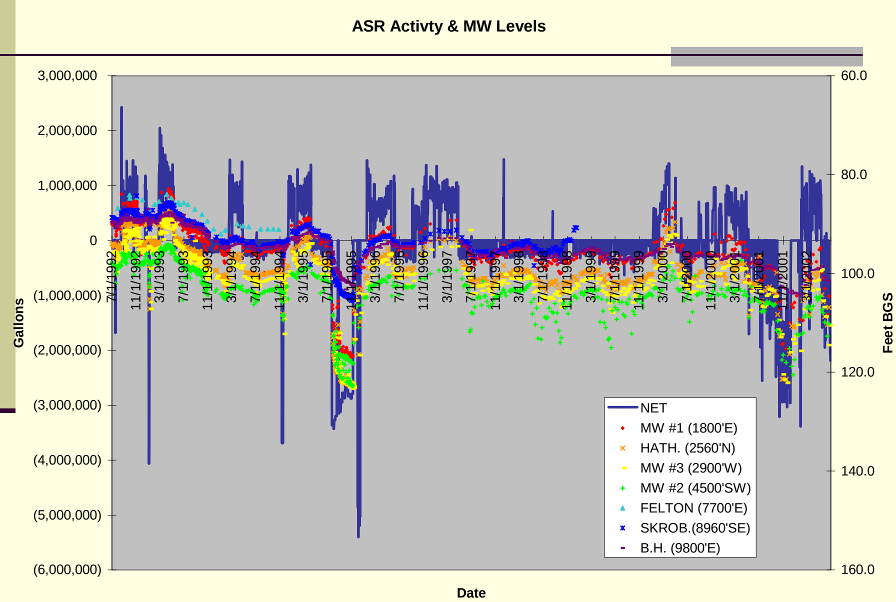
- need for more "dynamic" regional flow models
  - **CBIC**
  - brackish withdrawals
  - development of add-on modules (like optimization)

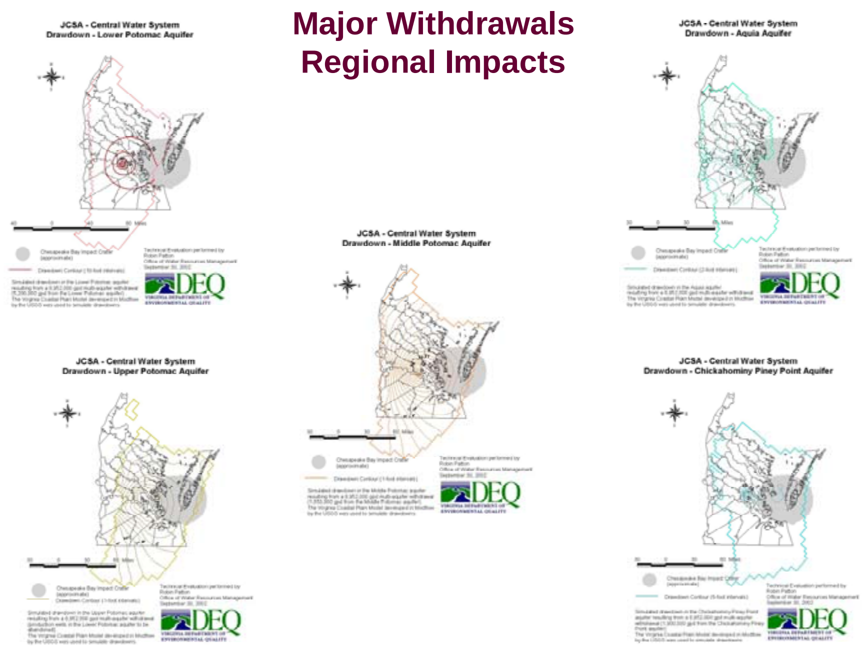


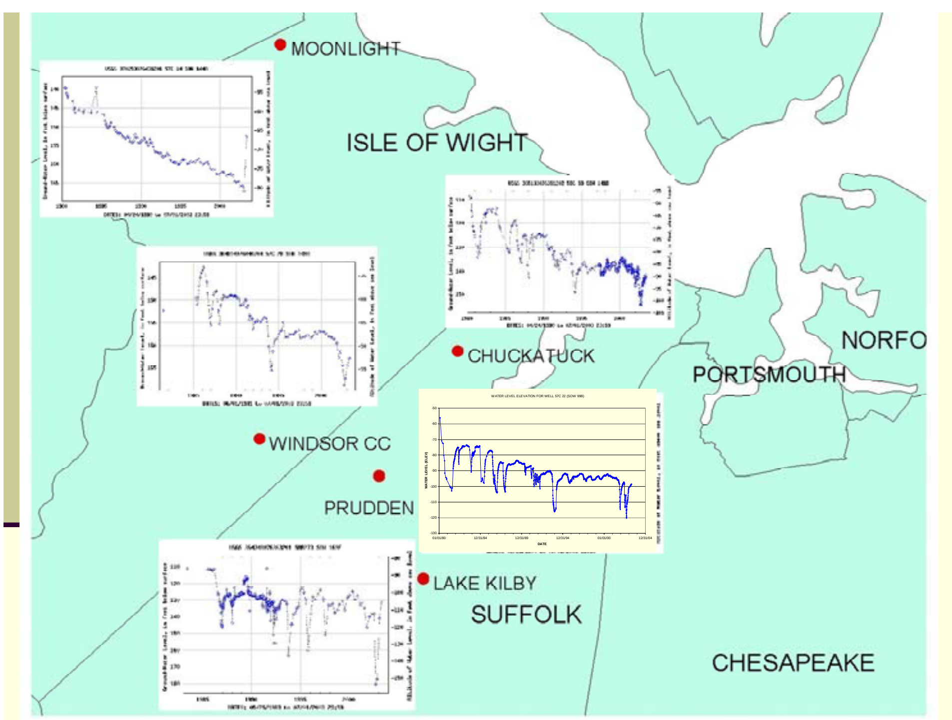
Issues over time

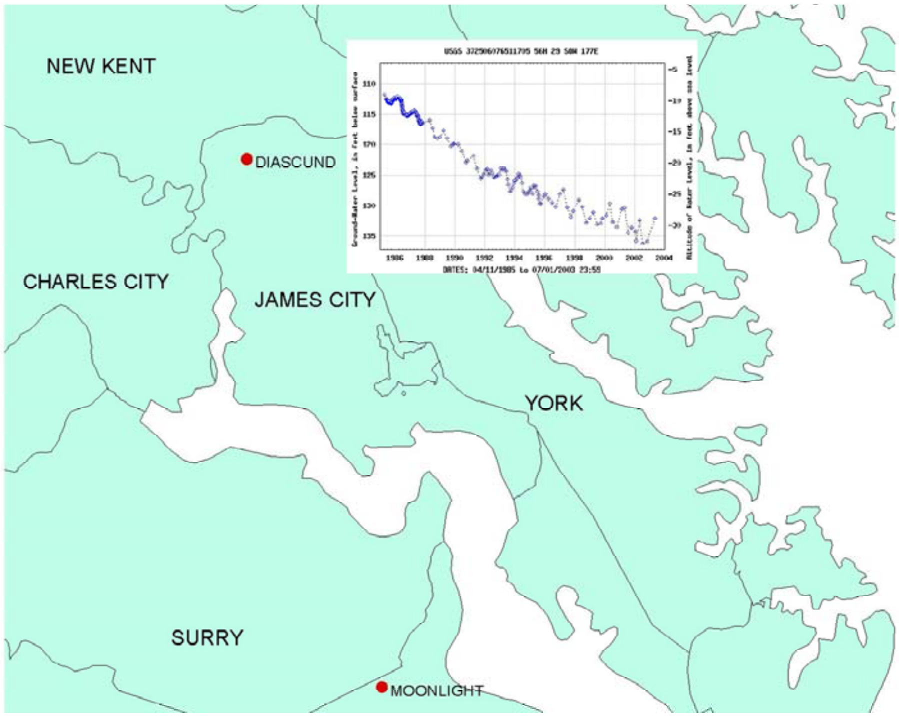
- unregulated withdrawals
  - domestic use – single home wells in subdivisions
  - coastal plain counties not in GWMA's
- interstate resource
  - MD
  - NC
- need for more "dynamic" regional flow models
  - CBIC
  - brackish withdrawals
  - development of add-on modules like optimization
- difficulties of generalization
  - intricacies of formations
  - pumping periods

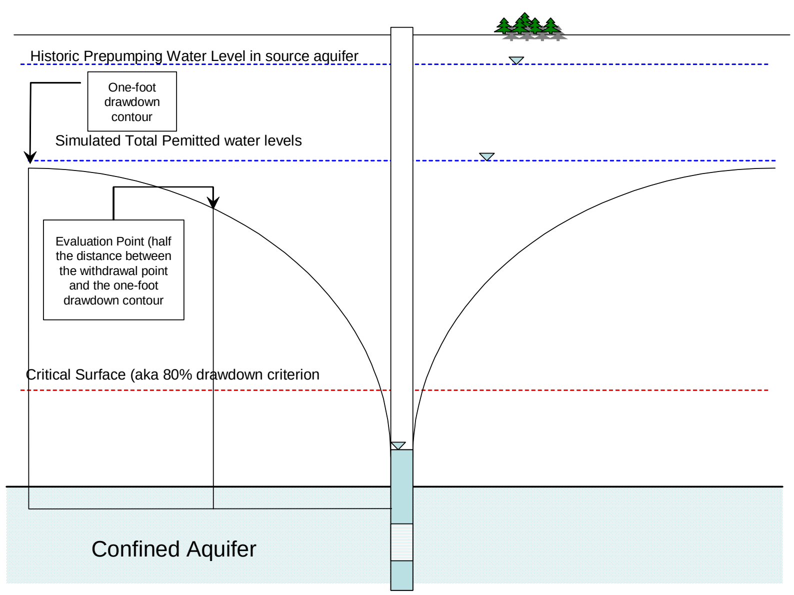
Regional System with Regional Impacts

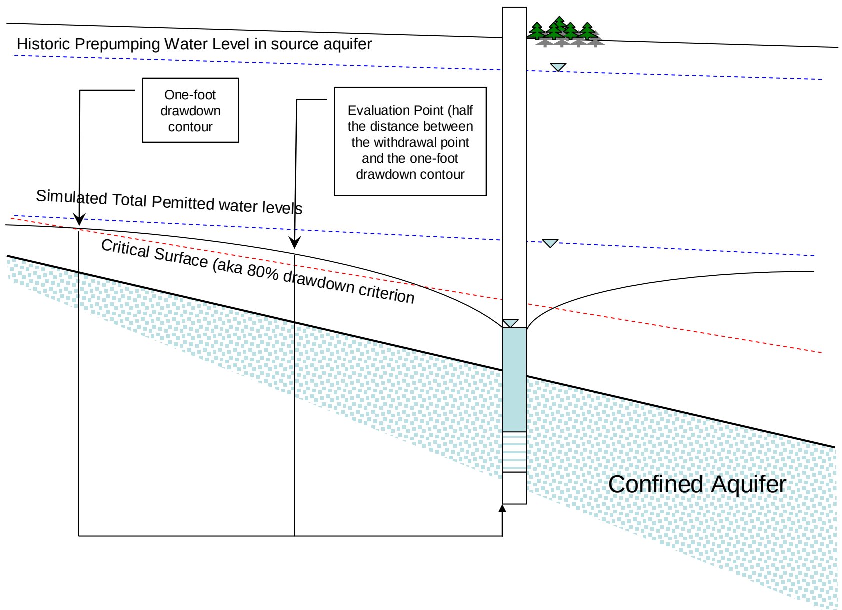



Major Withdrawals
Regional Impacts
JCSA - Central Water System
Drawdown - Lower Potomac Aquifer
JCSA - Central Water System
Drawdown - Aquia Aquifer
JCSA - Central Water System
Drawdown - Middle Potomac Aquifer
JCSA - Central Water System
Drawdown - Upper Potomac Aquifer
JCSA - Central Water System
Drawdown - Chickahominy Piney Point Aquifer
DEQ


MOONLIGHT
ISLE OF WIGHT
CHUCKATUCK
NORFO
PORTSMOUTH
WINDSOR CC
PRUDDEN
LAKE KILBY
SUFFOLK
CHESAPEAKE


NEW KENT
DIASCUND
CHARLES CITY
JAMES CITY
YORK
SURRY
MOONLIGHT


Historic Prepumping Water Level in source aquifer
One-foot drawdown contour
Simulated Total Pemitted water levels
Evaluation Point (half the distance between the withdrawal point and the one-foot drawdown contour
Critical Surface (aka 80% drawdown criterion
Confined Aquifer



Virginia Department of Environmental Quality

Water Resource Division

Terry Wagner, Director

Office of Ground Water Withdrawal Permitting

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RESEARCH PAPERS

SHELLFISH TMDLS IN VIRGINIA: SEDIMENT AS A RESERVOIR OF FECAL COLIFORMS?

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KEY WORDS: fecal coliform, shellfish growing waters, sediment, TMDL

ABSTRACT

Implementation of shellfish growing area Total Maximum Daily Loadings (TMDLs) assumes that identifiable and potentially controllable sources of fecal pollution exist within watersheds. Sediments have been implicated as reservoirs concentrating and promoting fecal coliform survival and as sources through resuspension from wind and tide-induced, episodic runoff, or vessels. Resuspension of bottom sediment leading to elevated fecal coliform levels has been observed in river and beach waters and potentially confounds interpretations of water column indicator density. The role of estuarine sediment with respect to shellfish TMDL programs has yet to be elucidated. One aspect of the research described herein was to measure the densities and settling rates of fecal coliforms using sediment from a condemned branch of the Poquoson River estuary, Virginia. Seasonal surveys established the magnitude and variation of the sediment *Escherichia coli* reservoir. Values for seasonal fecal coliform settling coefficients (K_{set}) following laboratory resuspension experiments and their short-term persistence after 3 and 6 days incubation at in situ temperatures were also determined. Overall results suggest that the sediment fecal coliform reservoir requires further evaluation and should be considered as a potential source factor in TMDL budgets. Results from this study may be useful to evaluate how well numerical models simulate resuspension of fecal coliforms to the water column.

INTRODUCTION

Fecal coliforms are ubiquitous in receiving waters of watersheds and coastal waters (Weiskel et al. 1996, Mallin et al. 2001). The relationship between fecal coliform densities and potential health risks is regulated by standards that are water based. Implementation of shellfish growing area Total Maximum Daily Loadings (TMDLs) assumes that identifiable and potentially controllable sources of fecal coliforms (fecal pollution) exist within watersheds and contribute to water column loading. For TMDL allocations of sources, domestic farm animals, and septic effluents can be identified and remediation steps taken to reduce inputs. Control of other sources, both external (growth in soils, wildlife) and internal (animals, sediment) is problematic. Sediments have been implicated as internal reservoirs concentrating and promoting fecal coliform survival or growth (Gerba and McLeod 1976, LaLiberte and Grimes 1982), and as sources to overlying waters through resuspension from wind and tide-induced currents, episodic runoff events, or vessels (Matson et al. 1978, Pettibone et al. 1996, An et al. 2002). Resuspension leading to elevated fecal coliform levels has been examined in beach sediments and potentially confounds the meaning of water column bacteriological results and public health risk (Shiaris et al. 1987, McLellan et al. 2001). The role of sediments within the context of the TMDL program remains unresolved. Fecal coliform densities in sediments are reported as orders of magnitude larger on a volume basis than those in the water column (Van Donsel and Geldreich 1971, Matson et al. 1978, Rhodes and Kator 1991). If surface growing area sediments contain fecal coliform concentrations larger than those in the water column, sediment as both a source of fecal coliforms to the water column and as a refuge for their removal should be considered in the development of a TMDL budget. Fecal coliform aftergrowth within a sediment refuge also has the potential to alter TMDL budgets.

One particular TMDL where sediment fecal coliforms could be important is the Poquoson River embayment. Two of the condemned areas in this system are shallow (mean depth <2 m) with waters characterized by relatively high fecal coliform densities. If resuspension effects vary indirectly with depth (Matson et al. 1978), such effects could be important in a shallow system like the Poquoson. Resuspension events capable of transporting sediment associated fecal coliforms into the water column do occur (e. g., Matson et al. 1978) but relating bacterial resuspension to controlling physical factors requires a considerable commitment of field resources (Webster and Lemckert 2002**)**. Accordingly, the intent of this research was to determine densities of fecal coliforms (as *E. coli*) in sediment as a function of season in a condemned shellfish growing area (Poquoson River embayment), to measure the short-term temporal stability of *E. coli* in resuspended sediments in vitro, and to assess the persistence of *Escherichia coli* in sediment. This information could benefit modelers trying to describe and evaluate the significance of an *E. coli* sediment reservoir on the TMDL process.

METHODS

The Poquoson coastal embayment is located along the western shore of the Chesapeake Bay about 4 km south of the York River mouth in Virginia. The Poquoson River and its branches are on the 1998 303(d) list as impaired for fecal coliform in shellfish harvesting waters requiring development of a TMDL. The dominant fecal coliform (FC) source in the Poquoson is nonpoint (Shen et al. 2002). Mean FC water concentrations in the northwest branch are well in excess of the shellfish growing area standard (14 FC MPN 100 ml^{-1}) (Shen et al. 2002).

Sediment samples were collected every other month by coring at six headwater stations along an approximately 1 km transect moving downstream from station 1 to station 6 in the condemned area of the northwest branch. No samples were collected during rain events or following within three days of rain events ≥1". Two pooled sediment samples each consisting of three independent cores were collected at each station for determination of fecal coliform (*E. coli*) sediment concentrations. The top 3 cm of each core was captured in a 3 cm high plastic ring (5.8 cm inner diameter) and transferred to a plastic bag. One water sample was collected at each station at mid-depth or 0.5 m below the surface at slack (high) water. Routine measurements consisted of water temperature, salinity and oxygen concentration. All samples were stored in the dark at ambient temperature prior to enumeration and experimental work. Samples were processed within 2-3 hours of collection.

There are no standard procedures for enumeration of *E. coli* from sediment. Sediment suspensions for *E. coli* density and settling determinations were prepared in large flasks (2 l) filled with a 1:10 dilution by weight of sediment (approx. 60 g) in site water by agitation at 200 rpm for 5 minutes on a temperature-controlled rotary shaker. Enumeration samples were removed at mid-flask depth (5 cm) within 15 –30 sec after stopping the shaker using a sterile pipet. Samples were enumerated using the IDEXX Colilert-18 system (IDEXX Laboratories, Inc., Westbrook, Maine) with QuantiTray/2000 multiwell analysis plates following the manufacturer's directions to dilute samples tenfold in distilled water prior to inoculation. Colilert-18 is specific for *E. coli*, has been approved by EPA for use in marine waters (2003), and used for sediment analysis in previous studies (Desmarais et al. 2002). Colilert-18 offers greater precision than a 10-tube MPN and a larger range before sample dilution is needed. Plates incubated at 35°C for 18-22 h were read using longwave UV illumination to detect MUG cleavage and equivalent *E. coli* MPN counts determined using the manufacturer's table. Water samples were enumerated as above. Counts were expressed as MPN 100 ml^{-1} water or MPN g^{-1} wet sediment. Sediment volume and wet weight were determined for each sample. A positive control consisting of an ATCC *E. coli* culture was used to verify Colilert-18 performance.

Experiments were also performed to measure the short-term stability of fecal coliforms in suspended sediment. Duplicate samples from each station collected bimonthly were used for this purpose. Immediately after agitation and removal of samples to measure *E. coli* densities, flasks were incubated statically at 23°C and the water phase sampled at 3 and 6 hours following the protocol above. Settling coefficients, $K_{set,}$ were calculated by linear regression from plots of ln *E. coli* count versus time. Duplicate bimonthly sediment samples from three stations (1, 3, and 6) were also incubated as intact wet sediment at average in situ field temperatures for 0, 3 and 6 day intervals in plastic bags. At each time interval a sample of sediment was processed for enumeration as described. Sediments were mixed by gentle kneading prior to sample removal.

RESULTS AND DISCUSSION

Results for water and sediment *E. coli* concentrations are shown in Figures 1 and 2. High *E. coli* densities found in water column samples corroborated prior data justifying a TMDL in the Poquoson. Surface sediments contained high densities of *E. coli* relative to the shellfish growing area standard. When compared on a equivalent volume basis, i. e., 1 gm of sediment = 1 ml water, mean *E. coli* counts over all stations and all seasons were 41x higher than the already elevated water column densities.

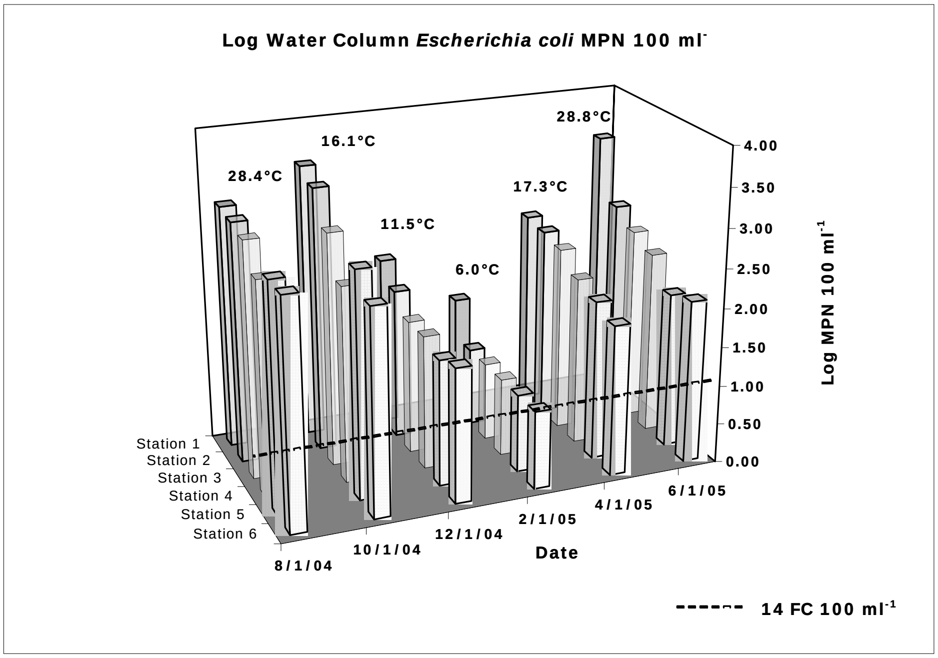

Figure 1. Surface water *Escherichia coli* densities, log MPN 100 ml^{-1}

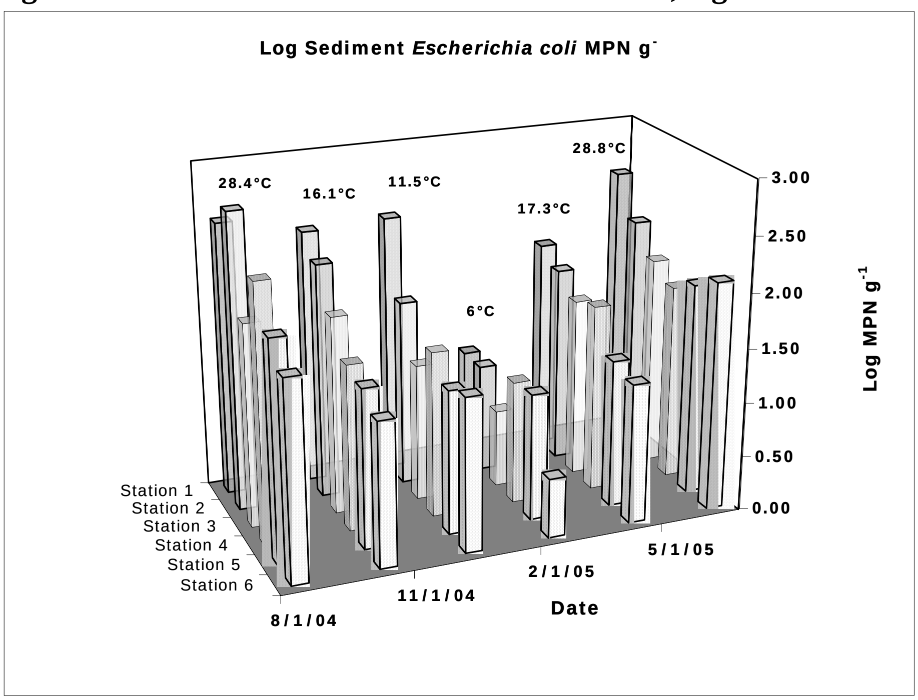

Figure 2. Surface sediment *Escherichia coli* densities, log MPN g^{-1} wet sediment.

Anticipated trends of decreasing *E. coli* densities with distance downstream and with seasonally low water temperatures were observed. An overall R value of 0.60 from simple correlation analysis (e. g., Pearson) of *E. coli* water column MPN against sediment MPN suggested a dynamic interaction existed between these two compartments. Using actual *E. coli* sediment densities one can grossly estimate the potential influence of resuspended sediment on sanitary water quality. Table 1 shows three scenarios illustrating the result of instantaneously suspending *E. coli* contained in a 1 m^2 plot of surface sediment underlying either 1 or 0.5 m^3 of estuarine water. The latter values simulating water depths of 0.5 or 1 m are appropriate for the shallow headwaters of the Poquoson. Except for February when the *E. coli* population were lowest, values exceeded the shellfish growing area standard.

Settling experiments revealed that suspended *E. coli* densities decreased rapidly over the six hour assay period. Settling rates varied with both station location and seasonal temperature, suggesting the stability of a given suspension was a complex function of physical, chemical and biological factors. Seasonal effects could be related to differences in growth, physiology, predation, enumeration, viscosity, particulate material and the behavior of organic matter. Tables 2 and 3 show values of k_{set} coefficients and T_{90} values (time required for a 90% reduction in *E. coli* density). Although settling coefficients calculated by linear regression were large relative to fecal coliform dieoff coefficients, the largest decrease occurred during the first three hours (overall ca. 0.5 log reduction) followed by a plateau during which there was little additional loss or even an increase (overall change 0.1 log unit). This suggests that a variable proportion of the *E. coli* cells were adsorbed or associated with large sediment particles which rapidly settled in the quiescent flasks. The plateau phase was reflected in the T_{90} values which in several instances exceeded a 12 hour tidal cycle. The rapid initial settling rate could be an artifact of the suspension process which was intended to maximize the efficiency of *E. coli* enumeration. Measurements of sediment actually suspended in the Poquoson if available could be used to compare and if necessary, adjust the laboratory suspension process toward field parameters.

Results to assess *E. coli* persistence in sediment incubated at ambient temperatures are shown in Table 4. It is difficult to generalize from these results as consistent patterns were not observed. Relative to initial levels, *E. coli* densities decreased in some sediments while in others levels increased or exhibited growth. Sediments typically display variable spatial heterogeneity in bacterial density and processes measurements. Longer term laboratory incubations are also sensitive to conditions that can limit growth. Nonetheless, T_{90} values calculated from data shown in Table 4 indicate significant potential for long term persistence or growth over the six day time period. Observations of after growth support the hypothesis that during seasonally elevated temperatures sediment could be a new source of fecal coliforms.

Table 1. Simulated water column MPN values (*Escherichia coli* MPN 100 ml^{-1}) obtained following suspension of 0.1 or 1 g surface sediment into two depths of overlying water.

Scenario	Date	Station 1	2	3	4	5	6
1 g suspended in 1 m^3	8/25/04	1430	2236	327	968	459	401
	10/18/04	970	617	292	142	129	130
	12/6/04	1052	219	80	142	94	159
	2/7/05	44	42	23	58	65	21
	4/11/05	386	277	199	227	102	119
	6/13/05	1525	646	381	270	398	772
0.1 g suspended in 1 m^3	8/25/04	143	223	32	96	45	40
	10/18/04	97	61	29	14	12	13
	12/6/04	105	21	8	14	9	15
	2/7/05	4	4	2	5	6	2
	4/11/05	38	27	19	22	10	11
	6/13/05	152	64	38	27	39	77
1 g suspended in 0.5 m^3	8/25/04	2860	4472.	654	1937	918	802
	10/18/04	1941	1235	585	285	259	261
	12/6/04	2105	439	161	285	189	319
	2/7/05	88	84	46.	116	131	43
	4/11/05	773	554	398	455	204	238
	6/13/05	3051	1292	763	540	797	1544

Table 2. Settling coefficients (K_{set}) for *Escherichia coli* suspended in Poquoson River water, where k_{set} is the rate of change in density following suspension of sediment and calculated by linear regression ($k_{set} = \ln X_1 - \ln X_0 / t_1 - t_0$). Units are h^{-1}.

Station	Date 8/25/04	10/18/04	12/6/04	2/7/05	4/11/05	6/13/05
1	-0.54	-0.28	-0.11	-0.11	-0.42	-0.54
2	-0.36	-0.27	-0.32	-0.32	-0.24	-0.38
3	-0.48	-0.28	-0.15	-0.15	-0.26	-0.42
4	-0.38	-0.22	-0.31	-0.31	-0.26	-0.48
5	-0.34	-0.12	-0.27	-0.27	-0.17	-0.53
6	-0.31	-0.21	-0.15	-0.15	-0.22	-0.49

Table 3. T_{90} times where $T_{90} = \ln(0.1)/k_{set}$. Units are hours.

Station	Date					
	8/25/04	10/18/04	12/6/04	2/7/05	4/11/05	6/13/05
1	5.5	8.3	6.0	21.1	5.5	4.2
2	9.8	8.4	5.0	7.2	8.0	6.0
3	8.4	8.1	6.3	15.0	8.9	5.4
4	8.8	10.6	16.4	7.5	8.7	4.8
5	13.6	18.6	5.0	8.5	13.4	4.3
6	10.5	10.8	9.7	15.4	10.6	4.7

Table 4. ***Escherichia coli*** **persistence (log MPN g^{-1}) in intact sediment samples incubated at average seasonal temperatures under laboratory conditions.**

Date	Incubation Temperature °C	Days Incubated	Average Log MPN/g Site		
			1	**3**	**6**
8/25/04	28	0	2.37	1.64	1.67
		3	1.75	1.02	0.41
		6	1.75	1.31	1.24
10/18/04	16	0	2.15	1.56	1.19
		3	2.27	1.68	3.12
		6	1.06	0.78	2.05
12/6/04	12	0	2.17	1.10	1.35
		3	2.20	0.87	1.39
		6	2.00	0.83	1.00
2/7/04	6	0	0.80	0.62	0.40
		3	1.03	0.56	0.00
		6	1.04	0.49	0.00
4/11/04	17	0	1.74	1.44	1.12
		3	1.54	0.95	1.11
		6	0.85	0.84	0.48
6/13/04	29	0	2.42	1.77	1.97
		3	3.02	3.05	3.38
		6	2.44	2.02	3.41

Settling coefficients and sediment *E. coli* densities from this study were used in preliminary assessments of how adding these parameters to a linked watershed/hydrodynamic model with a sediment submodel (Shen et al. 2002) would predict FC water concentrations. In the absence of other sources of fecal coliforms, resuspension initially increased bacterial levels in the water column to values as high as 300 MPN 100 ml^{-1}. However, the model was very sensitive to sediment settling velocity and suspended bacteria were rapidly removed as the settling velocity dominated the removal process. This implies the model does not accurately capture the partitioning of bacteria into free and adsorbed forms and therefore overestimates loss of *E. coli* due to settling. Future efforts should be directed toward understanding this partitioning.

CONCLUSIONS

1. Concentrations of *Escherichia coli* in surface sediments from a condemned branch of the Poquoson River exceeded on a per volume basis levels in the water column. Concentrations were highest during the warmer months. The magnitude of the *E. coli* sediment reservoir suggests it can affect water sanitary water quality under appropriate conditions.

2. Under laboratory conditions simulating a resuspension event, large reductions in suspended *E. coli* cells occurred within 3 h and were presumably associated with settling of large particles. However, a significant proportion of the initial cell population remained in suspension for at least 6 h.

3. In vitro experiments showed *E. coli* could persist or grow in sediment under seasonally elevated temperatures over a six day incubation period.

4. Preliminary use of a numerical model incorporating *E. coli* sediment densities and settling coefficients showed that sediment resuspension could affect sanitary water quality. Efforts should be directed toward improved understanding of the proportion of bacteria adsorbed to sediment particles to better model the settling process.

5. The combination of high *E. coli* densities and persistence in surface sediment with naturally-occurring resuspension events strongly suggests that sediment-associated *E. coli* in the Poquoson embayment can influence sanitary water quality and should be evaluated as a source factor in TMDL budgets.

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IDENTIFICATION OF NATIVE BROOK TROUT STREAMS THAT ARE IMPAIRED BY ACIDIFICATION

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KEY WORDS: acidification, atmospheric deposition, impaired streams, pH, brook trout

ABSTRACT

Although it is well established that many of Virginia's native brook trout streams have been acidified due to atmospheric deposition (acid rain), relatively few of these streams have been included in impaired streams listings by the Virginia Department of Environmental Quality. Whereas most of the available pH data for these streams have been obtained by lab analysis, in situ or field analysis is required for purposes of water quality assessment. This project addressed this deficiency by obtaining one year of monthly pH data in the field by approved methods for 20 of Virginia's most-acidic native brook trout streams. Nineteen of these streams met the applicable criteria (pH <6.0 or pH <6.5) for impairment due to acidity. In addition, field and lab measurements of pH were compared to evaluate the use of lab pH to predict violations of the general statewide minimum pH standard of 6.0. For the type of streams included in this study, and for analysis up to 29-30 days following sampling, it can be predicted with at least 99% certainty that field pH is <6.0 when lab pH is $\leq$5.79, and that field pH is >6.0 when lab pH is $\geq$6.33. Recommendations include: (1) development of a screening tool for the use of lab pH to identify acidification-impaired surface waters; and (2) development of water quality standards, in addition to standards based on pH and benthic data, for the specific identification of impairment due to atmospheric deposition.

INTRODUCTION

The mountain headwater streams that provide habitat for the native brook trout (*Salvelinus fontinalis*) are among the most highly valued of the Commonwealth's water resources. Although these streams are generally protected from degradation that can be characterized as direct anthropogenic impact, it is well documented that water quality and faunal diversity in a substantial number of these streams have been altered by acidification related to atmospheric deposition (Webb *et al.* 1989; Cosby *et al.* 1991; Bulger *et al.* 2000). It is also apparent that current efforts to control air pollution have not achieved substantial improvement in the condition of these streams (Stoddard *et al.* 2003; Webb *et al.* 2004). However, the effects of atmospheric deposition have only recently been recognized in water quality assessments and impaired streams listings prepared by the Virginia Department of Environmental Quality (DEQ).

The 2004 Combined Water Quality Assessment and Impaired Streams Report (DEQ 2004) identified 20 streams for which the source of impairment is believed to be atmospheric deposition. Available data indicate that the actual number of Virginia streams that are impaired due to atmospheric deposition is much higher. For example, pH values <6.0 have been observed for 22% of the approximately 450 native brook trout streams for which data are available through the Shenandoah Watershed Study and the Virginia Trout Stream Sensitivity Study (SWAS/VTSSS) programs conducted by the Department of Environmental Sciences at the University of Virginia. Although pH values <6.0 violate the general statewide pH standard of 6.0-9.0 (9 VAC 25-260), the SWAS/VTSSS data do not comply with EPA rules (40 CFR 136), which effectively require analysis of pH in the field. The DEQ is thus unable to use the extensive lab pH data available through the SWAS/VTSSS and other programs.

The rule that only field pH data are acceptable for water quality assessments may be overly restrictive. Reliable pH measurement in the field is difficult in a context of limited time and resources. Previous work involving dilute waters of the type represented by Virginia's brook trout streams has shown that the in situ pH for most waters is lower than the pH determined for samples in the lab (Kaufmann *et al.* 1988). Thus, for brook trout streams for which lab pH values are less than a minimum criterion value, the actual stream pH is probably as low or lower.

Regardless of the practical significance of field versus lab pH analysis, the DEQ adheres to methods requirements. As a result, most of the brook trout streams that are affected by acidification have not been included in the DEQ listings of impaired waters, and thus they are not subject to the potential benefits of the TMDL (Total Maximum Daily Load) process, which involves development and implementation of plans to achieve water quality improvements.

OBJECTIVES

The first objective was to obtain pH data for a number of native brook trout streams in Virginia using methods that conform to EPA and DEQ requirements for identification of surface waters impaired due to acidity. The second objective was to examine pH stability or differences between field and lab pH measurements.

PROCEDURES

Streams studied through the SWAS/VTSSS programs were ranked based on previous lab pH values. From among the streams with the lowest pH values, 20 streams were selected for measurement of pH in the field (Figure 1). Sampling was organized by assigning the study streams to "routes" that were each followed at monthly intervals during a period of twelve months (Water Year 2004). The analysis method conformed to the requirements established in 40 CFR 136. Data quality assurance was provided by calibration with NIST traceable buffers at each data collection site and adherence to a protocol involving analysis of multiple aliquots and application of stability criteria (SWAS/VTSSS 2005).

The study of differences between field and lab pH measurements involved in situ measurement of pH and collection of samples for pH measurement in the lab. Lab measurements were obtained at four points in time, including 1-2, 8-9, 15-16, and 29-30 days after field measurement. The samples for lab analysis were collected at the same sites and same times that field pH measurements were obtained, with separate samples collected for each subsequent lab analyses. Three sites were selected for both field and lab measurements in each of four quarters. The samples were collected in prewashed 500 ml LDPE Nalgene bottles. The samples were

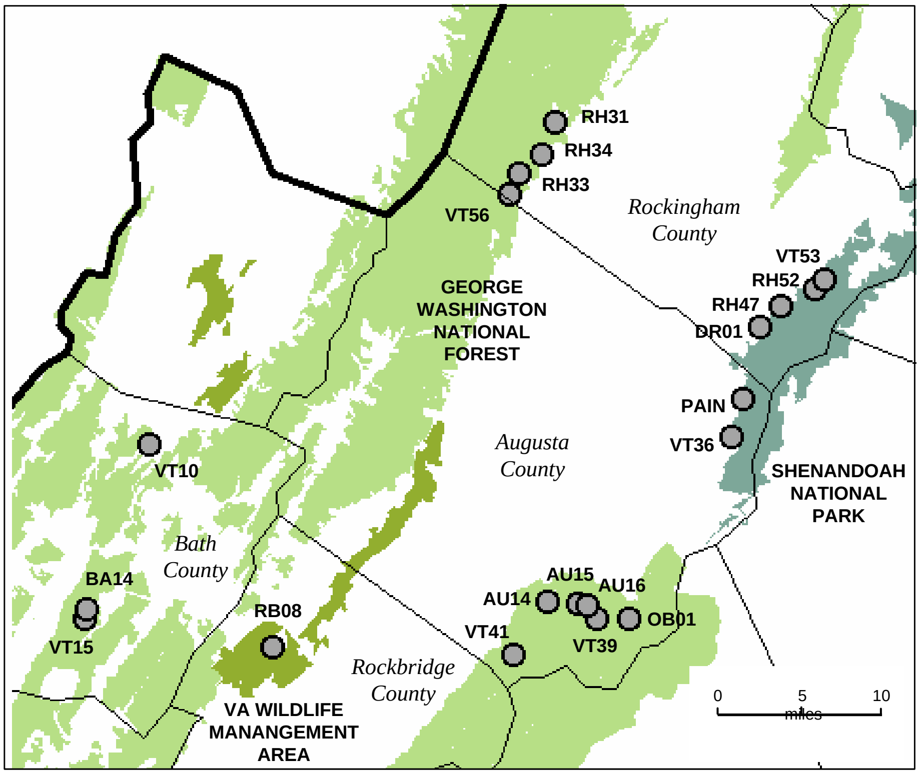

Figure 1. Native brook trout stream data collection sites in western Virginia. See Figure 2 for stream names.

placed in insulated containers with refrigerant when collected and placed in a refrigerator upon return to the project lab. Prior to analysis, the individual samples to be analyzed were removed from the refrigerator and allowed to attain room temperature. The protocol for lab analysis was the same as for field analysis with respect to calibration, analysis of multiple aliquots, and application of stability criteria.

RESULTS

The project provided data to evaluate 20 of Virginia's native brook trout streams in relation to the pH criteria established for identification of impaired waters. The number of values obtained per stream ranged from 10 to 14, with at least 12 monthly values obtained for 19 of the streams. Time series plots of pH values obtained for the 20 streams are provided in Figure 2.

A stream is considered impaired if the values of 10.5% or more of the available data violate the applicable water quality standard and there are at least two violations (DEQ 2004). The general statewide pH standard is 6.0-9.0, with 6.5-9.5 specified for certain streams, including many native brook trout streams (9 VAC 25-260). Nineteen of the study streams met the applicable criteria for designation as impaired by acidification.

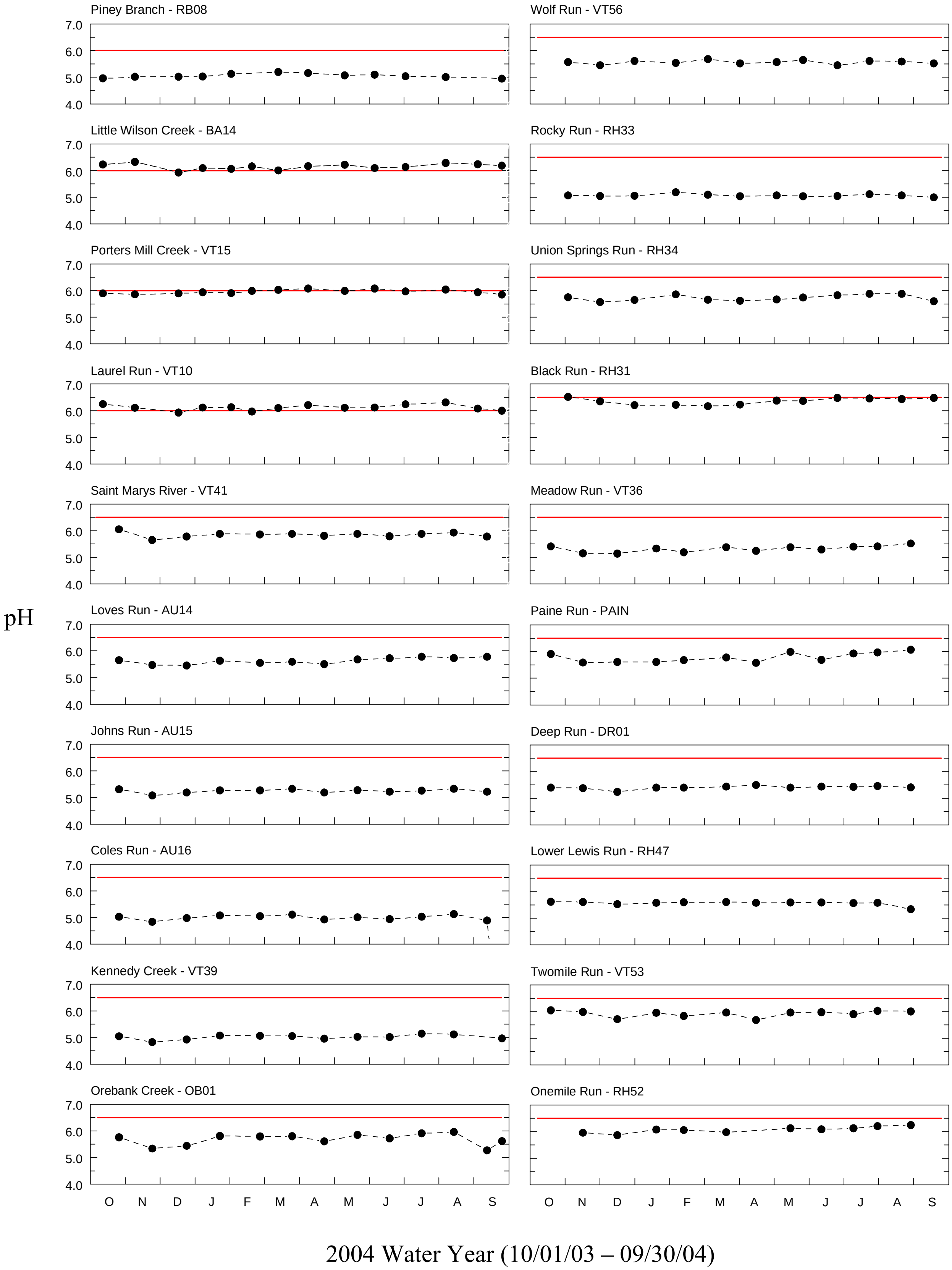

Figure 2. Field pH. The stream-specific minimum pH criteria for impairment (6.0 or 6.5) are indicated by the red lines.

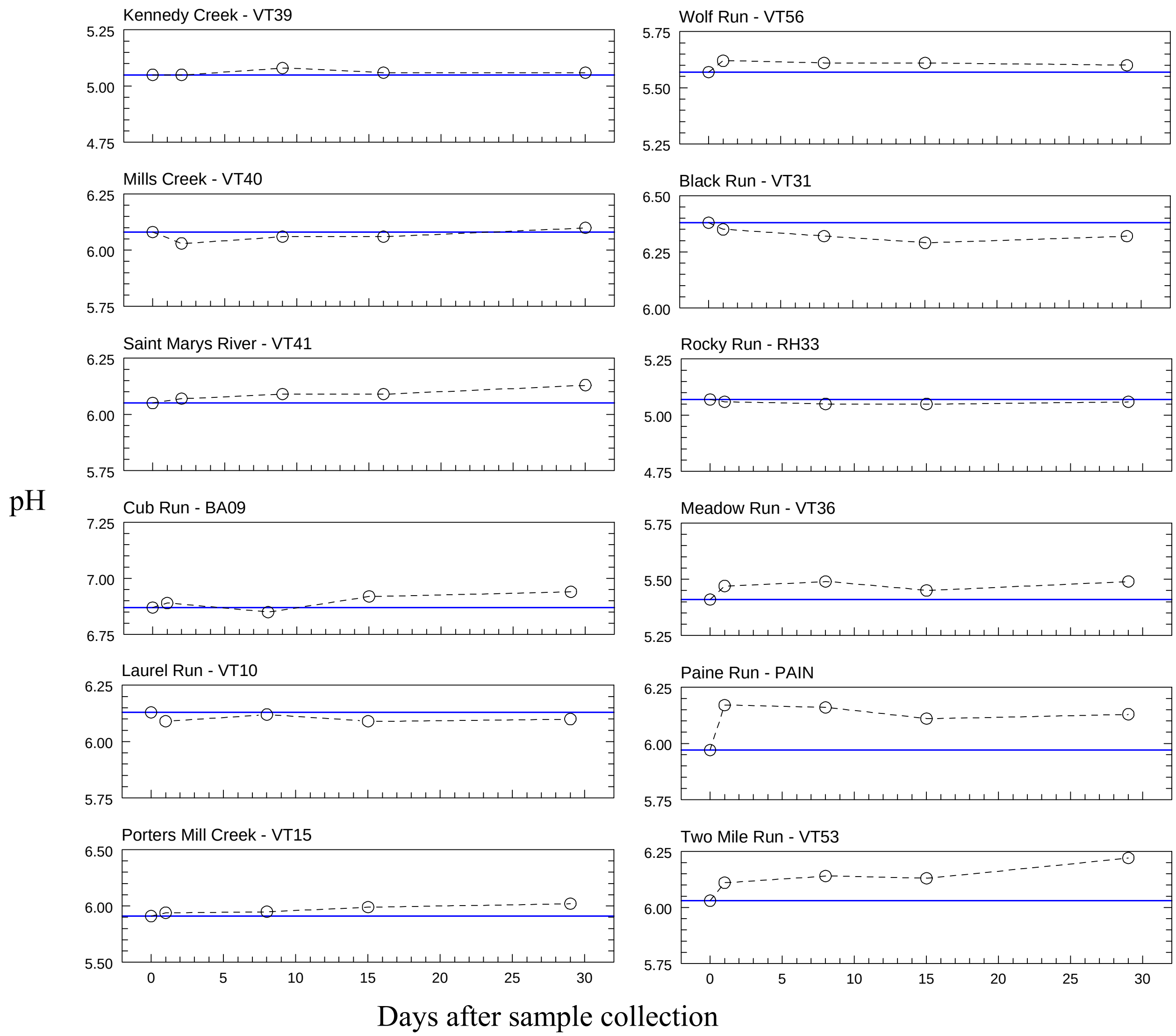

Figure 3. Stability test results. Initial (field) pH values are indicated by the blue lines.

The data obtained during the stability component of the project are provided in Figure 3. The range of deviations between lab and field measurements for all 12 study streams was -0.09 to +0.20 pH units. Figure 4 provides regression equations for field pH with lab pH obtained at different intervals. Confidence intervals for predicted values provide a basis for estimating: (1) the lab pH at or below which there is 99% certainty that the field pH is <6.0; and (2) the lab pH at or above which there is 99% certainty that the field pH is >6.0. These estimated values are:

- For analysis 1-2 days after sampling: 5.79 and 6.27.
- For analysis 8-9 days after sampling: 5.79 and 6.28.
- For analysis 15-16 days after sampling: 5.80 and 6.26.
- For analysis 29-30 days after sampling: 5.79 and 6.33.

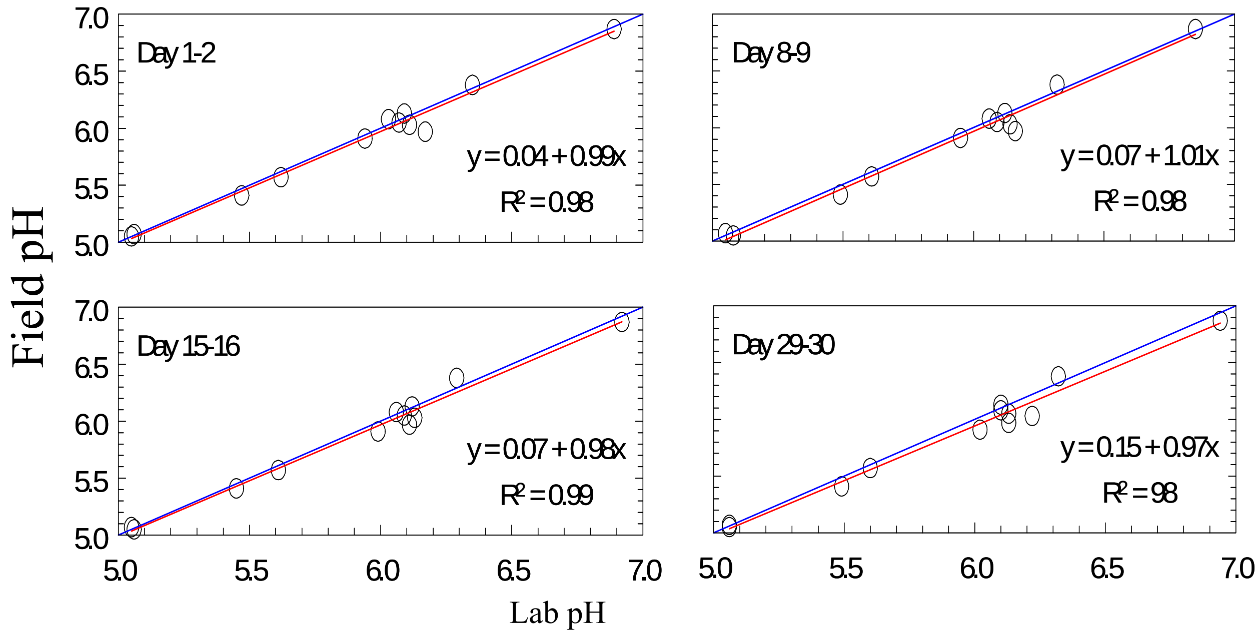

Figure 4. Regressions of field pH with lab pH. The plots represent different intervals following field pH measurement and sampling. Regression lines are indicated by the red lines; 1:1 correspondence is indicated by the blue lines.

DISCUSSION

A principal reason that the DEQ water quality assessments do not effectively account for stream acidification due to atmospheric deposition in Virginia's mountain streams is the lack of approved pH data. Of the 20 streams identified as impaired by acidification due to atmospheric deposition in the most-recent impaired streams listing, 13 were identified as impaired based on benthic data (DEQ 2004). Only seven were identified as impaired based on measurement of stream water pH. For five of these seven streams, the identification of impairment was based on only two available pH measurements. It is apparent that few pH data are being obtained for Virginia mountain streams by methods that meet the DEQ and EPA requirements.

We have addressed this data deficiency by collecting pH data by approved methods and submitting these data to the DEQ. The submitted data support the listing of 19 native brook trout streams as impaired by acidification, including 14 streams not listed in previous impaired streams reports. For the five streams listed in previous reports, the data provide a stronger basis for assessment, increasing the number of available pH measurements from two to 12 for three streams and providing 12 pH measurements for each of two streams for which benthic data, but no pH data, were previously available.

We also examined the data obtained through the stability component of the project to evaluate the use of lab pH to estimate field pH. We were primarily concerned with differences between field and lab pH that would result in either failure to identify an impaired stream or incorrect identification of an impaired stream. The confidence intervals determined for prediction of field pH with lab pH provide a basis for quantifying the probability of making these errors. For the type of streams examined in this study, and for lab analysis conducted up to 29-30 days following sampling, we can conclude with 99% confidence that field pH is less than the general statewide standard of 6.0 if the lab pH is 5.79 or lower, and that field pH is greater than 6.0 when the lab pH is 6.33 or higher. This suggests that a reliable screening tool can be developed to allow preliminary evaluation of stream impairment based on lab pH measurement. However, the development of a broadly useful screening tool would require more information than provided by the current study, which involved a small sample size (n = 12) and a relatively narrow pH range. Only one stream included in the study had pH values greater than 6.5, which is the standard for many of Virginia's native brook trout streams. Thus the development of a screening tool designed for general application to native brook trout streams would require information based on streams representing a broader range of pH.

Development of a screening tool for prioritizing collection of pH data by approved methods would address a significant data deficiency and thereby contribute to more-effective consideration of atmospheric deposition effects in Virginia's water quality assessment program. However, it should be recognized that assessments based on reference to a pH standard are inherently limited, and that for those native brook trout streams that have been identified in DEQ assessments as impaired by acidification, the attribution of cause is not definitive. This is reflected in stream-specific fact sheets, which indicate that the impairment source for these waters is "believed to be" atmospheric deposition (DEQ 2004). The underlying problem is that neither low pH, nor evidence for acidification-related impairment of the benthic community, provides a sufficient basis for identification or assessment of atmospheric deposition effects.

The primary pollutants associated with atmospheric deposition are acidic sulfur and nitrogen compounds, and water quality effects are determined by watershed conditions and processes that govern the transport and neutralization of these compounds (see Galloway *et al*. 1983; Webb 2004). The impact of atmospheric deposition and the mitigating effects of these watershed factors are indicated in surface waters by the concentrations and ratios of solutes derived from the atmosphere (e.g., sulfate and nitrate) and solutes derived from watersheds (e.g., calcium ion and magnesium ion). We propose that reliable identification of impairment due to atmospheric deposition will involve consideration of these solutes, in addition to pH and benthic data.

CONCLUSIONS

1) Although acidification due to atmospheric deposition is a well-documented problem for Virginia's native brook trout streams, it is a problem that has not been effectively addressed in Virginia's water quality assessment reports and impaired streams listings.
2) Although collection of reliable pH data by approved methods is difficult, such data collection is feasible, as demonstrated by collection of pH data on a monthly basis during a one-year period for 20 native brook trout streams in western Virginia.

3) Although lab measurement of pH is not approved for use in Virginia's water quality assessment program, a study of differences between field and lab measurements suggests that lab pH can be used to estimate field pH.

RECOMMENDATIONS

1) A screening tool should be developed to allow the use of lab pH measurement for preliminary evaluation of stream impairment and prioritization of follow-up data collection.
2) Water quality standards, in addition to standards based on pH and benthic data, should be developed for the specific identification of impairment due to atmospheric deposition.

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EXPLORING ENERGY SLOPE, PARTICLE SHEAR STRESS, AND STREAM FLOW USING SYSTEM DYNAMICS MODELING

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KEY WORDS: modeling, feedback, system dynamics, stream flow, energy, sediment transport

ABSTRACT

The critical hydraulic conditions for the beginning of sediment motion, and associated stream channel shear stresses have been extensively studied. The feedback dynamics associated with water surface energy slopes, particle shear stresses, and hydraulic geometry are, however, often overlooked.

This paper highlights a simulation model designed to illustrate these interactions. Inter-connections at the catchment scale are used to simulate changes in parameters caused by single or multiple storm events. Diagrams and graphs show the dynamic consequences of changes in mean water surface width, mean water depth, and mean water velocity as well as changes in shear velocity and hydraulic radius. The effects of interactions among various water runoff, stream discharge, channel slope, and streambed particle size distribution scenarios may be compared.

A system dynamics model can capture and explain the structure, causal loops, feedback, and non-linear dynamics that are part of a natural system. System dynamics models are useful aids to managerial planning and scenario analysis.

INTRODUCTION

We live in a world that organizes itself using feedback processes that continuously change states of ecosystem organization. While stream and river systems are often conceptualized as fundamentally "open" systems, moving through the landscape as a result of converting the potential energy of elevation to the kinetic energy of motion as water travels from mountains to sea, feedback processes even within this context cause stream channel and water column to interact and shape the stream bed, which in turn determines the efficiency of water movement and rate of sediment production.

Much of this feedback is caused by interactions among water, bed material, channel shape, and water surface slope. Within the context of an historic and over-arching energy slope, or change in elevation from mountains to sea, these four components interact to help create the physical conditions observed in a stream or river. A change in one of these elements can influence the others.

System dynamics modeling can be used to accurately identify these interconnections and simulate the effects of changes. The modeling process relies on a characterization of the structure of the dynamic system that is producing the behavior of interest. A map showing structural links is created, equations are used to describe relationships among links, and computer simulation is used to "set things in motion," allowing changes in system components, caused by other system components, to play out over time. With a useful representation of system structure in hand, past and future changes may be simulated. This makes system dynamics modeling an informative aid to management decision-making.

The system dynamics model presented here identifies key components and structural links among water, bed material, channel shape, and water surface slope. These interact to create changes in water surface energy slopes, particle shear stresses, and hydraulic geometry. Important characteristics of a system dynamics model include identification of positive and negative feedback loops and any delays imbedded within the system.

METHODS

The causal loop diagram in Figure 1 shows some of the major interconnections among the components of this feedback system. Equations were written describing each link. A computer was used to process the equations. The simulated outcome was displayed in graphs showing change over time. At least three feedback loops may interact to create the dynamics associated with sediment motion in stream channels.

During a typical rainfall event, precipitation within a watershed increases the volume of water discharged into a stream channel. This change causes the water surface within a typical stream reach to widen and the mean depth of water to increase. As the water surface widens, the wetted perimeter of water coming into contact with the channel may increase. The area of water within a typical stream cross section also increases. The hydraulic radius (water cross sectional area divided by the wetted perimeter) may increase or decrease depending on the shape of the channel cross section. Thus, channel shape is one key to dynamic stability or instability within a channel reach. These associations are shown in Figure 1.

The actual dynamics associated with sediment movement can get quite interesting! As flow rates and water quantities change within the context of the channel's unique geomorphology and bed particle size distribution, conditions may be determined by any of at least three fundamental feedback loops imbedded in the system. Two of these tend to be self-reinforcing (positive) feedback loops that build on themselves. One loop is a compensating (negative) feedback loop that, when dominant, may serve to slow changes in the system.

If mean storm water velocity increases beyond a critical shear velocity threshold then significant streambed movement may occur and sediment may be produced. As streambed and bank shear velocities are exceeded, bed and bank erosion may take place. Over time this process may serve to both incrementally lengthen the channel and slightly decrease channel slope. Lower channel slopes and changes in hydraulic radius may serve to decrease shear velocities, which in turn may *increase* streambed and bank erosion. This reinforcing feedback process is shown as Loop A in Figure 1.

In similar fashion increased mean stream water velocities may serve to pick up and transport larger streambed particles, causing a net increase in streambed particle size distribution. The increased particle sizes may, in turn, help increase near bank shear velocity thresholds, decreasing streambed and bank erosion, and sediment discharge. If, however, the increased stream water velocities transport and deposit particles that are on average smaller, rather than larger than before, this feedback process can work to decrease shear velocity thresholds, increasing streambed and bank erosion, and sediment discharge. Much is contingent upon the initial conditions within the stream system and any shift in the size of mobilized particles as water flow increases. This reinforcing feedback process is shown as Loop B in Figure 1.

Finally, as increasing mean stream water velocities cause streambed and bank erosion, channel lengthening and lowering may result over time, producing a lower channel slope. Since water velocity is partially determined by channel slope, the net slope reduction may contribute to slowing mean rates of water movement. Slower water velocities and less energy in the system can serve to reduce bed and bank erosion and regulate change, establishing a new state of dynamic equilibrium in the stream reach. This compensating feedback process is shown as Loop C in Figure 1.

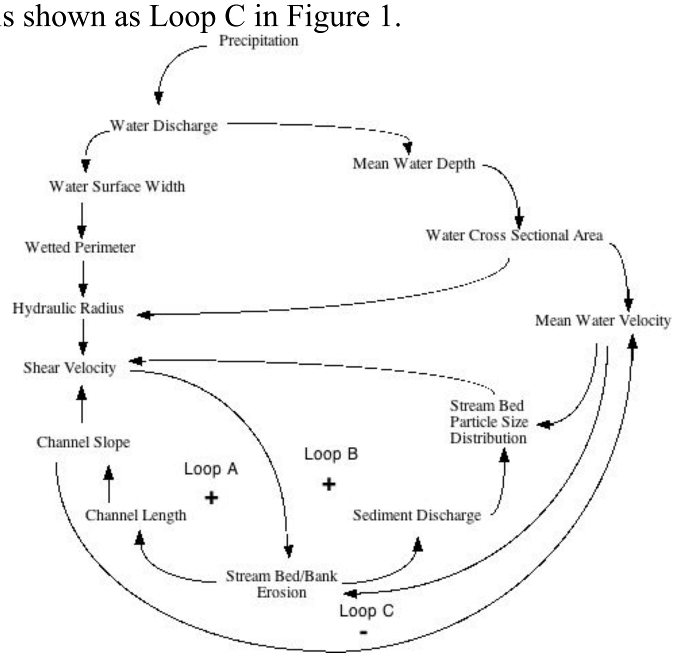

Figure 1: A Causal Loop Diagram Showing Significant Feedback Loops Associated With Sediment Movement in Stream Channels

RESULTS

Two simulated scenarios help illustrate the feedback dynamics embedded in these systems. Only the amount of rainfall is changed in scenario 2 relative to scenario 1. All other initial conditions are the same. The first scenario simulates stream channel response to two moderate rainfall events. Each is a simulated 1.5-inch rainfall, spread over the watershed above a fictitious Rosgen Class A2 stream and modeled using a typical NRCS Type II rainfall distribution. The resulting changes in stream response are shown in Figure 2. Mean water velocities and critical shear velocities fluctuate during each rainfall event. However, at no time do water velocities exceed the shear velocities needed to scour and mobilize streambed and bank armor. As a result, only small amounts of relatively fine sediments are entrained (Figure 2: Curve 4). Critical shear velocities stay below the threshold expressed by the Shield's curve (Figure 3: Curves 1, 2, 3, 5).

A second scenario simulates stream channel response to two larger rainfall events. Each is a simulated 3.5-inch rainfall, spread over the watershed above a fictitious Rosgen Class A2 stream and modeled using a typical NRCS Type II rainfall distribution. The resulting changes in sediment response are shown in Figure 3. As before, mean water velocities and critical shear velocities fluctuate during each rainfall event. This time, water velocities do exceed the shear velocities needed to scour and mobilize the larger particles that armor streambed and banks. As a result, relatively large amounts of sediments of varying sizes are entrained and moved, (Figure 3: Curve 4). The quantities of sediment mobilized during the second storm event increase as compared to the first storm as shifts in streambed particle size distributions result in entrainment of greater amounts of more easily moved particles. Critical shear velocities peak above the threshold expressed by the Shield's curve (Figure 3: Curves 1, 2, 3, 5).

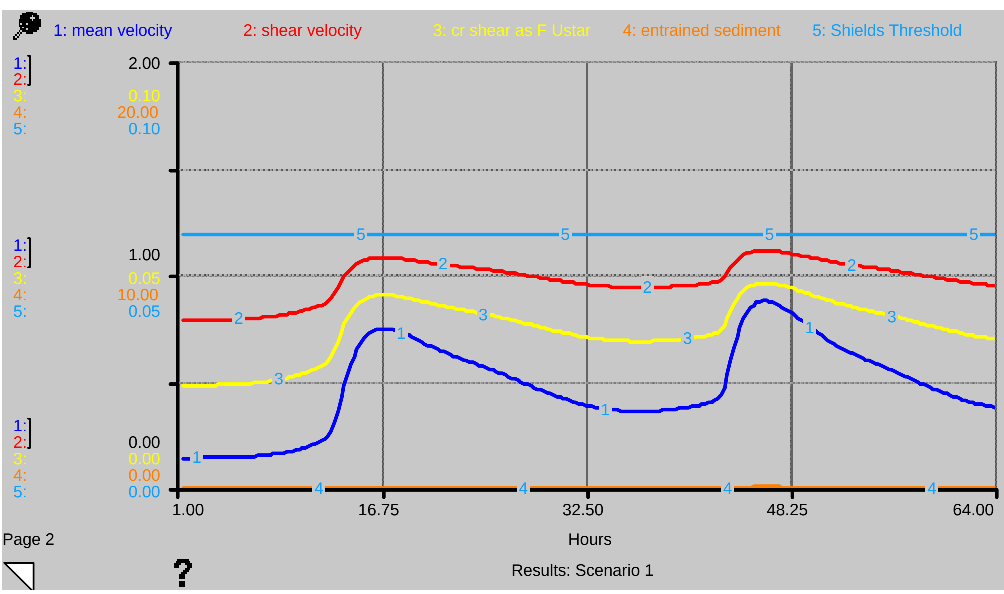

Figure 2: Results From Scenario 1

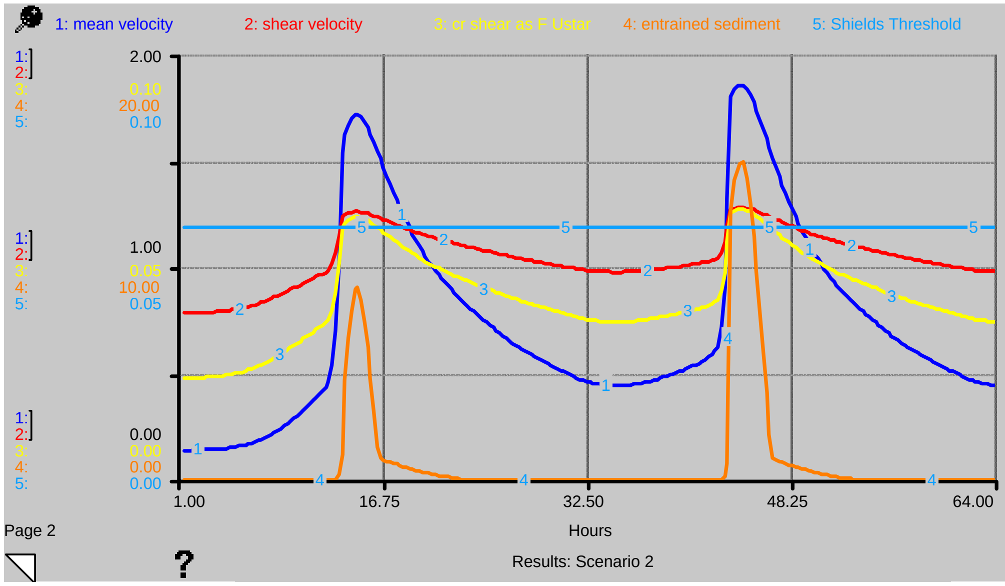

Figure 3: Results From Scenario 2

DISCUSSION

Many facets of the interconnectedness and dynamics associated with water energy slope, particle shear stresses, hydraulic geometry and stream flow are illuminated using a system dynamics feedback perspective. A number of the most important include the dynamic nature of shear velocities and stresses, the key role played by the hydraulic radius of the channel cross section, the effects of changing particle size distributions, and the feedback control embedded in stream system adjustments of channel slope.

As illustrated in the graphs of scenarios 1 and 2, mean water velocities, shear velocities, and the critical shear stress expressed as a function of shear velocity all change with water flow. While changing rates of water flow may be something we are all aware of, the dynamic nature of shear velocity and critical shear stress may come as a surprise. As demonstrated here, accurate modeling of these fluctuations can provide information critical to managing and protecting stream and river systems.

Feedback modeling identifies the significant influence of channel cross-section hydraulic radius on stream reach stability, and instability. Since hydraulic radius can be computed as water cross sectional area divided by the wetted perimeter, an increase in wetted perimeter can *decrease* hydraulic radius which, in turn, can lower the shear velocities necessary to initiate sediment movement. Conversely, an increase in cross sectional area can increase hydraulic radius, which can raise the shear velocities needed to initiate sediment movement. Since wetted perimeter and water cross-sectional area may each increase or decrease relative to the interaction between water flow and channel shape, complex and unexpected changes in shear velocity and sediment movement may result, (see Figure 1, Loop A).

Shifts in streambed particle size distribution significantly influence channel stability and sediment production. Channels evolve a balance of stream bed particle sizes and channel form that, for a given energy slope, work to move water and sediments efficiently and distribute and dissipate the energy of this motion uniformly along the entire length of the channel. Shifts in streambed particle size distribution resulting from new sediment inputs, channel modifications, or changes in water flow or timing, can alter this dynamic equilibrium. Depending upon the type of change that occurs, a new particle size distribution may cause shear velocity to increase or decrease, leading to either more or less streambed and stream bank erosion, and increasing or decreasing sediment discharge. Shifts in particle size distribution are often tightly linked to mean water velocities and the relative sizes of available substrate at, or just below the surface of the streambed, (see Figure 1, Loop B).

Changes in channel slope can redefine the energy gradient that controls movement of sediment and water and provides a balanced dynamic equilibrium. If channel slope increases, as a result of stream straightening or other disturbances, mean water velocities will increase, streambed and bank erosion may increase, and channel lengthening may occur. Channel lengthening will reduce channel slope, allowing the stream to reclaim its historic energy gradient and dynamic equilibrium. If channel slope decreases, as a result of streambed and bank erosion or channel lengthening, then mean water velocities will decrease. Reduced water velocities may in-turn lessen bed and bank erosion allowing establishment of a new, less efficient, dynamic equilibrium based on a lower energy gradient, (see Figure 1, Loop C). Depending on the circumstances, significant sediment transport efficiencies may also be lost. This often happens when channel slope reductions and changes in channel cross-sectional shape, such as widening, occur simultaneously, essentially activating Loop B in Figure1. Reduced sediment transport efficiencies can result in smaller sediments remaining in the channel, leading to shifts in streambed particle size distributions, which lower the shear velocities needed to move a less course sediment. An increase in sediment load and sediment deposition may result.

This is one simple example of using system dynamics modeling as an aid to understanding the intricacies of water flow and sediment movement through open, natural channels. Model structure and parameters may be closely fitted to conditions found within specific watersheds and channel types. Detailed analyses may be readily performed and communicated describing the past and future consequences of management actions, land use change, water flow pathways, storm history and severity, and historical trends. System dynamics modeling lends itself nicely to the description of non-linear continuous feedback systems, the very systems imbedded in so many natural processes.

Note: For purposes of this discussion, the energy dynamics of river and stream systems are highlighted and conceptualized as “open” with gravity and precipitation influencing these systems, without being influenced by them. In fact, the feedbacks that link rivers, precipitation, and gravity may exist in a larger, global, geologic context, where rivers influence available potential energy by weathering mountains, and the evaporation that creates precipitation is influenced by rates of flow and quantities of river water.

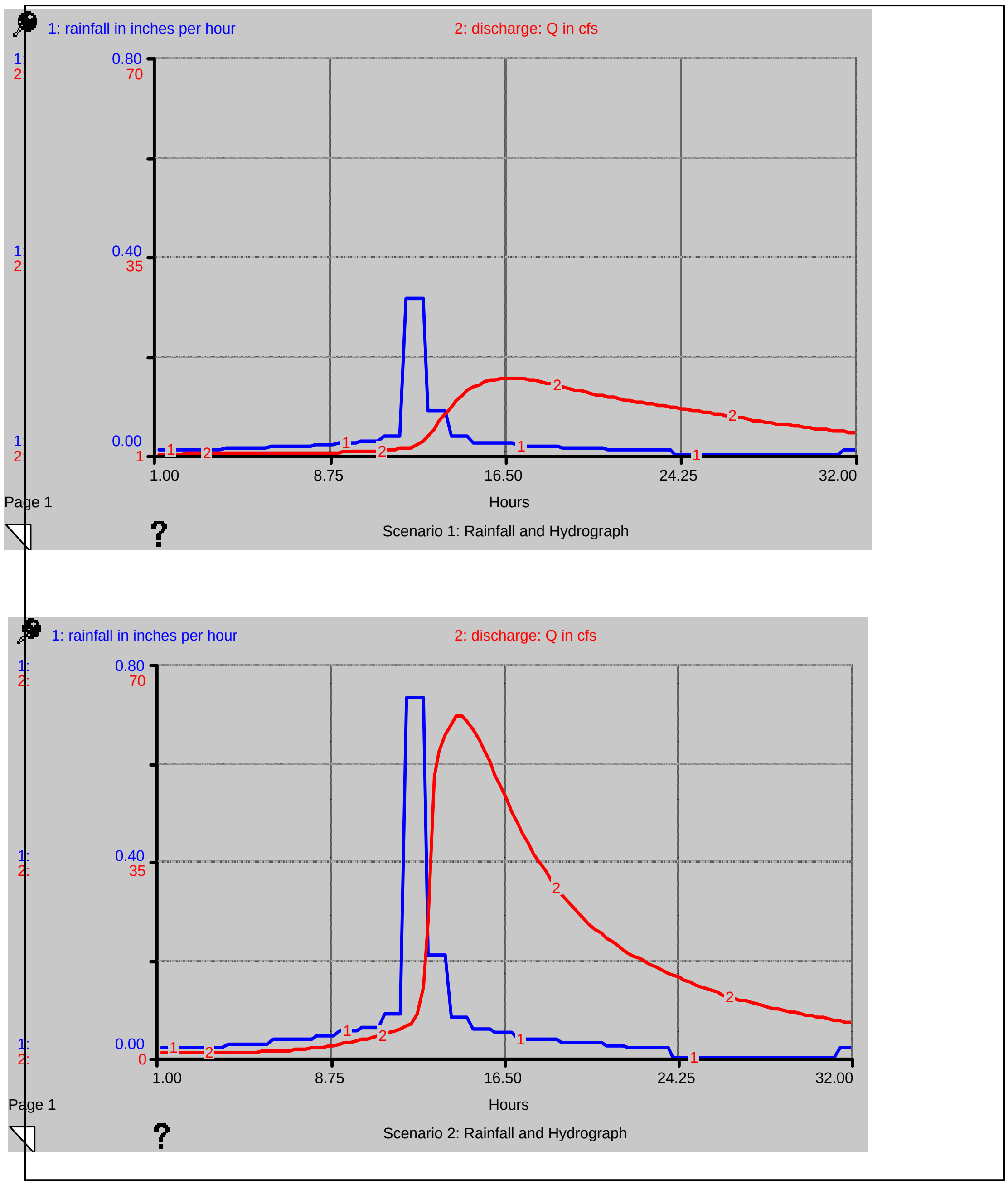

Figure 4: Rainfall and Stream Discharge as Modeled in Scenarios 1 and 2

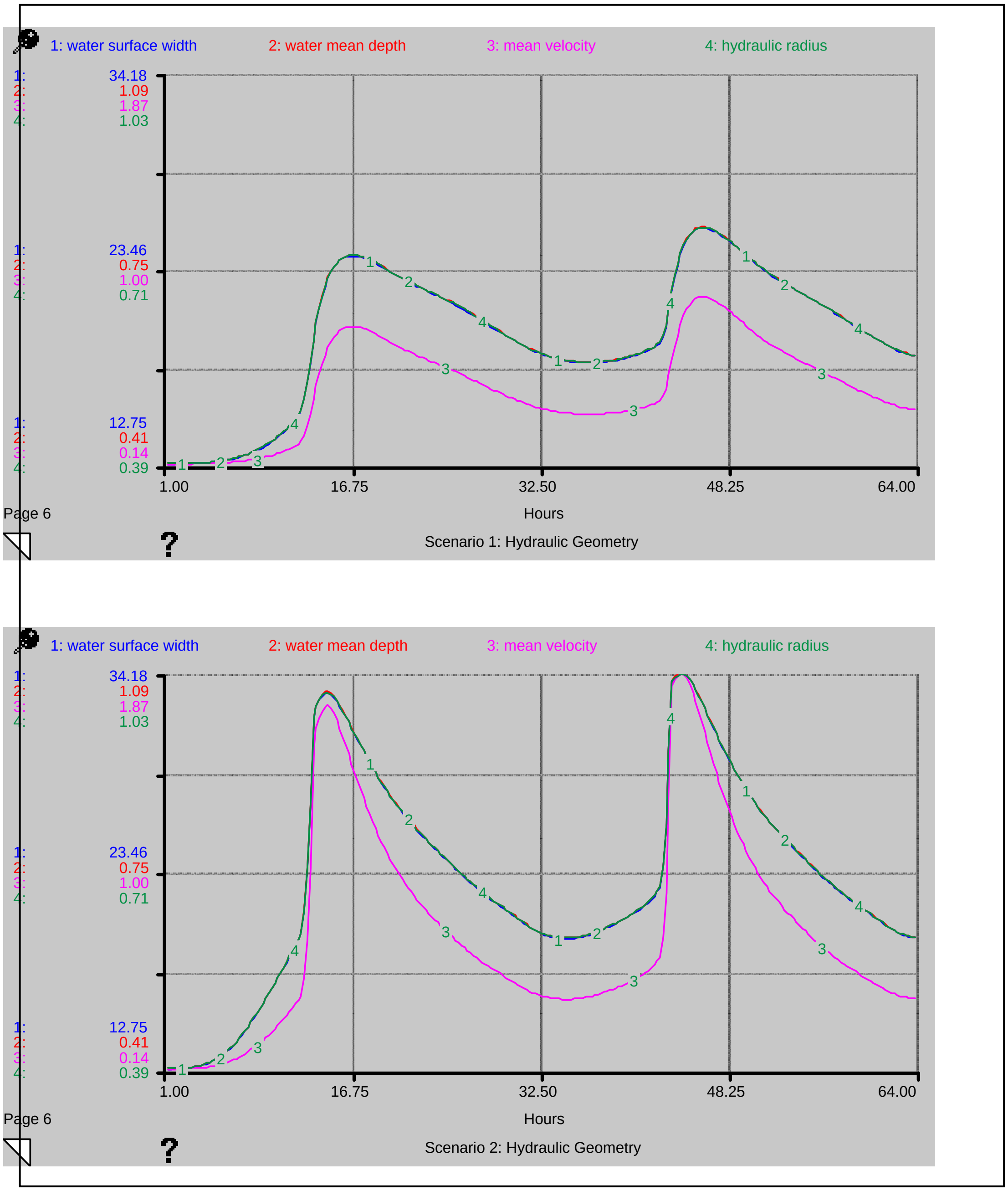

Figure 5: Dynamic Change in Hydraulic Geometry as Modeled in Scenarios 1 and 2

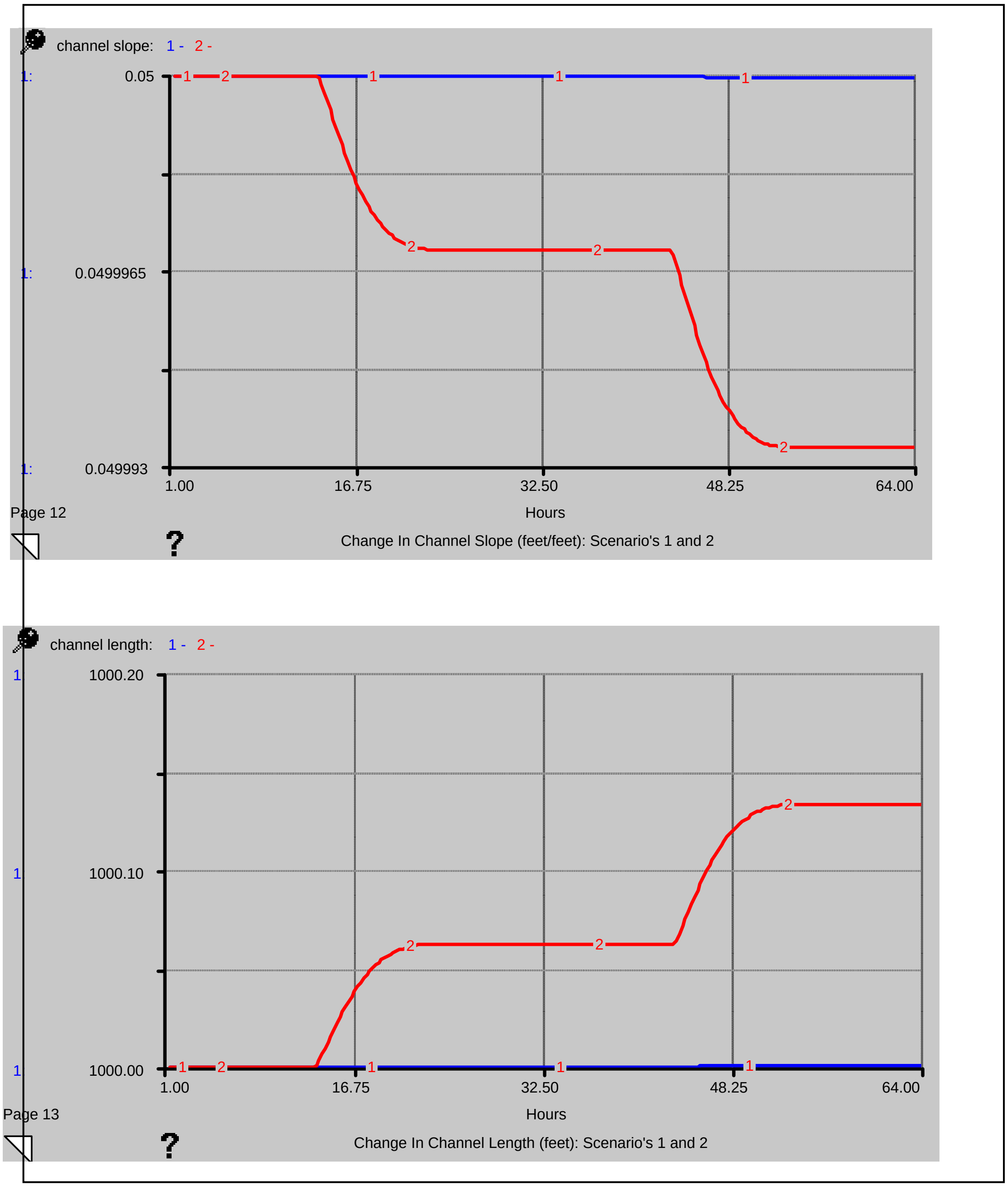

Figure 6: Change in Channel Slope and Channel Length as Modeled in Scenarios 1 and 2

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PERFORMANCE OF OPTICAL DISSOLVED OXYGEN SENSORS IN A SEVEN SITE, MIXED MATRIX STUDY

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KEY WORDS: optical dissolved oxygen

ABSTRACT

In the summer of 2004, the Alliance for Coastal Technologies (ACT), held a seven-site, mixed matrix performance evaluation of dissolved oxygen (DO) sensors. ACT is a NOAA-funded partnership designed to serve as an unbiased, third-party testbed for evaluating new and developing sensor and sensor platform technologies.[1] Prior to the technology evaluation, ACT held a workshop on the Development and Application of Dissolved Oxygen Sensors. The workshop focused on the available DO technology and newer developing technology, including strengths and weaknesses. Participants included researchers using DO sensors in studies of estuarine and coastal waters, coastal water quality managers, and industry representatives.[2] Table 1 shows a workshop summary of strengths and weaknesses of various DO sensing technologies considering different variables. Upon conclusion of the workshop, it was decided by ACT that a multiple site equipment evaluation would be worthwhile. Protocols, criteria and quality assurance procedures were agreed upon, and a testing time frame was set. Monitoring instruments were deployed during the summer of 2004, and final reports were released in December 2004. Instruments were deployed for 1 month in various surface water conditions ranging from fresh water to seawater, cool temperatures to warm temperatures, high physical fouling to low fouling environments. Table 2 shows the test sites along with the salinity and temperature conditions typical for the duration of the testing. Optical DO sensors were expected to exhibit superior performance to standard electrochemical sensors in this study. Table 3 show compiled results of the study (results table was not produced by ACT).

Theory of Optical DO Sensor Operation

Optical DO sensors rely on lifetime-based fluorescence technology to accurately measure DO levels in-situ. Lifetime-based measurements involve selected substances that can act as dynamic fluorescence quenchers. If a ruthenium-based complex (lumiphore) is illuminated with a blue LED in the absence of oxygen, it is excited and emits back a red luminescent light with a lifetime that is well characterized (Figure 1). The lifetime of the lumiphore's fluorescence is a physical constant of the complex, and does not change or degrade over time. Under typical environmental conditions, oxygen molecules act as dynamic fluorescence quenchers by absorbing energy from the lumiphore, causing it to drop back to its initial state of non-fluorescence more quickly than in anoxic conditions (Figure 2). This lifetime can be measured very accurately and correlated to dissolved oxygen concentrations. There is no consumption of oxygen during the interaction with the lumiphore, and therefore optical DO sensors do not require sample flow for accurate readings—unlike electrochemical sensors. Additionally, optical DO sensors have no membrane or electrolyte to degrade or foul. The lumiphore of the optical sensor is long-lived—in some cases requiring replacement only once every 5 years.

Table 1

Variable	**Galvanic**	**Polarographic Steady State**	**Polarographic Pulsed**	**Optical Steady State**	**Optical Life**
Flow Dependence	Low	High	Low	None	None
High Pressure Hysteresis (over 500m)	Yes	Yes	Yes	No	No
Response Time (to 90%)*	Slow	Medium	Medium	Fast	Fast
Range (0-200%)	Yes	Yes	Yes	Yes	Yes
low end (0-1 ppm)	❖	❖	❖	❖❖	❖❖
high end (20 ppm)	❖❖	❖❖	❖❖	❖❖	❖❖
Long Term Stability	❖	❖	❖	❖❖	❖❖
Frequency of Maintenance	High	High	High	Low	Low
Calibration					
zero point required	No	No	No	No	No
factory or laboratory	F	F/L	F/L	F	F
difficulty	N/A	Medium	Medium	N/A	N/A

*Slow ~ 7 minutes, Medium < 1 to 3 minutes, Fast < 1 minutes

❖❖Indicates better performance than ❖

State of Technology in the Development and Application of Dissolved Oxygen Sensors, Alliance for Coast Technologies (ACT) Workshop Proceedings, Savannah, Georgia, January 2004; University of Maryland Technical Report series No. TS-444-04-CBL, p.11.

Table 2

Basic Test Site Descriptions and Field Conditions During Testing			
ACT Partner Test Site	**Basic Characterization**	**Range in Water Temperature (^oC)**	**Range in Salinity (ppt)**
Bayboro Harbor, FL	An estuary in the southwest region of Tampa Bay	26.4-31.8	4.4-24.2
Belleville Lake, MI	A freshwater impoundment on the Huron River	22.5-27.1	0.0-0.1
Koneohe Bay Reef, HI	A high energy barrier coral barrier reef	25.1-28.7	34.4-34.9
Moss Landing, CA	An estuarine tributary of the Salinas River in Monterey Bay	14.0-17.3	30.9-33.5
Skidaway Island, GA	A subtropical estuary on the Skidaway River on the western shore of the Skidaway Island	23.8-29.8	18.4-30.9
Walpole, ME	A tide dominated Embayment/ Damariscotta River estuary	13.1-18.7	29.6-31.2

Table 3. ACT Evaluation – Summary of Results

Parameter	Winkler Titration	Optical DO	Polarographic	Galvanic
Average Initial Error, mg/L (net bias)	-	0.19	0.55	0.22
Frequency of Initial Errors 0.2 mg/L or Less	-	50%	40%	10%
Frequency of Initial Errors 2.0 mg/L or More	-	0%	10%	60%
Instrumental Spread at start of tests, mg/L		0.9	3.1	9.5
Individual Precision	0.22%	0.11%	0.11%	0.18%
Typical Drift during 1st Week, mg/L	-	0.39	0.77	1.01
Variability of Drift (worst up – worst down), mg/L	-	0.58	3.94	0.74
Worst Case # of Days of Good Data before Error	-	14	3	8

How accurate was it at the beginning?

Do the instruments match each other?

How bad was the drift?

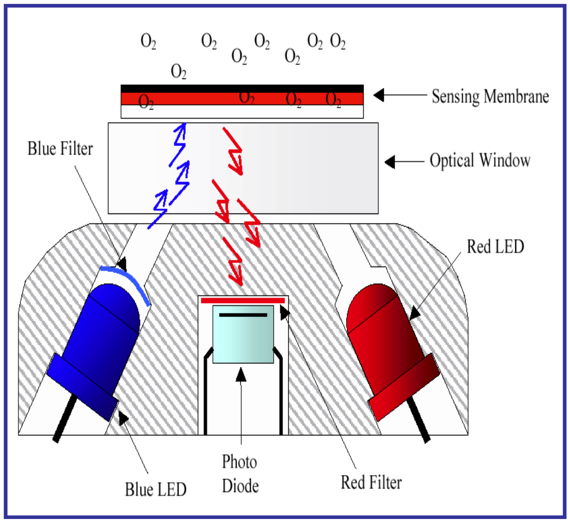

Figure 1

Delrin and Titanium Optical DO sensors

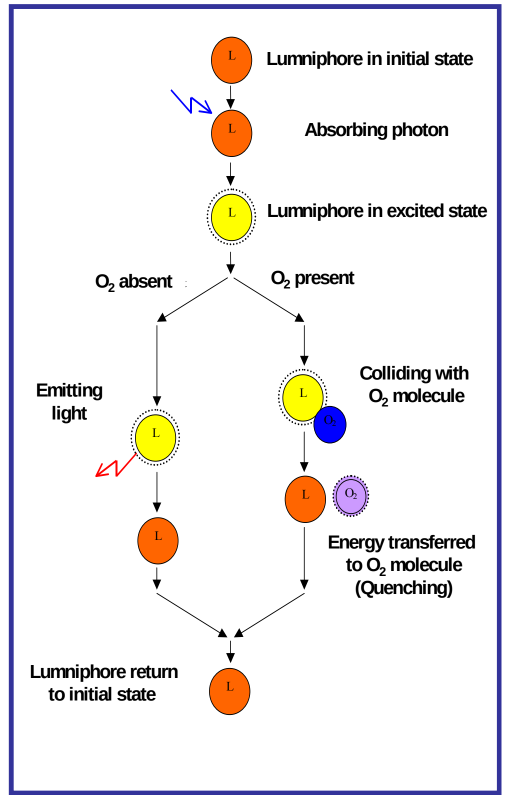

Figure 2

Quality Control / Quality Assurance

Laboratory testing was performed to determine instrument initial accuracy, precision, and sensor drift over a 1-month period.

Accuracy

For accuracy testing, the mean of 3 replicate instrument readings was compared to the mean of 3 replicate Winkler titrations. Samples were run under 36 distinct water conditions that varied in temperature, salinity, and dissolved oxygen. Figure 3 shows the results of the instrument DO values versus the Winkler titrations. The dotted line represents a 1:1 relationship. R-squared value was 0.999.

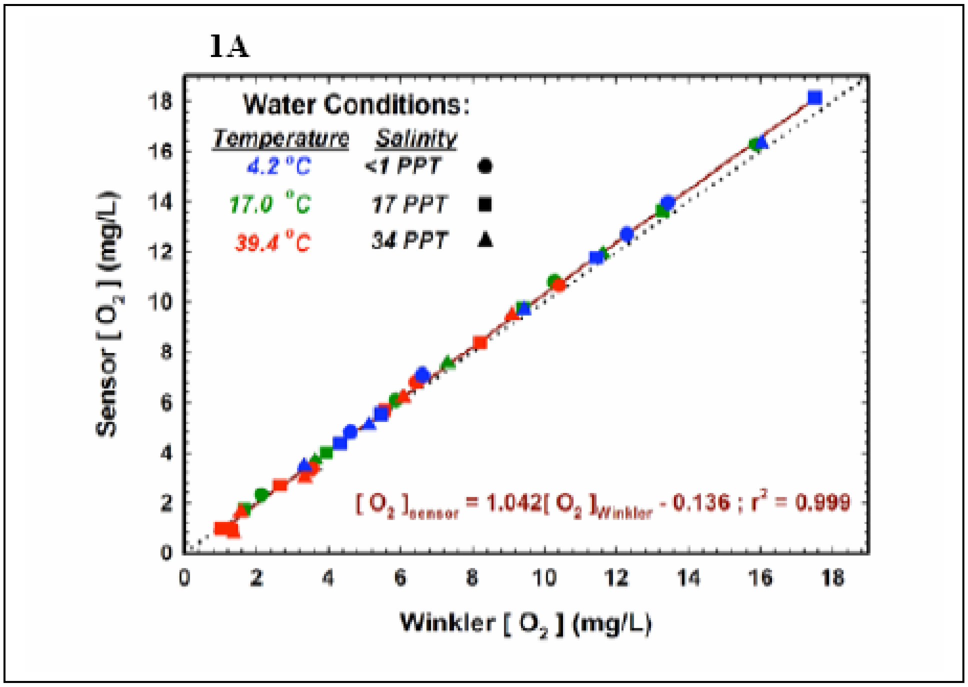

Figure 3

Precision

Laboratory precision testing was performed on a freshwater bath at 17.2°C, which was continuously aerated and held at or near 100% saturation. The mean, standard deviation, and coefficient of variance were generated from 30 replicate Winkler titrations of water samples taken from the bath, and 30 replicate instrument readings, taken simultaneously with the Winkler samples. (Table 4)

Table 4

Winkler DO			Optical DO		
Mean	STD	CV	Mean	STD	CV
8.97	0.02	0.22%	9.37	0.01	0.11%

Drift
Laboratory Instrument drift was measured by recording data from 2 instruments over a 1-month period and comparing to the mean of three replicate Winkler titrations. Both instruments exhibited an initial high offset of approximately 4.2%, indicating an error in calibration. However, both instruments showed superb linearity and minimal drift over the entire month of testing. (Figure 4)

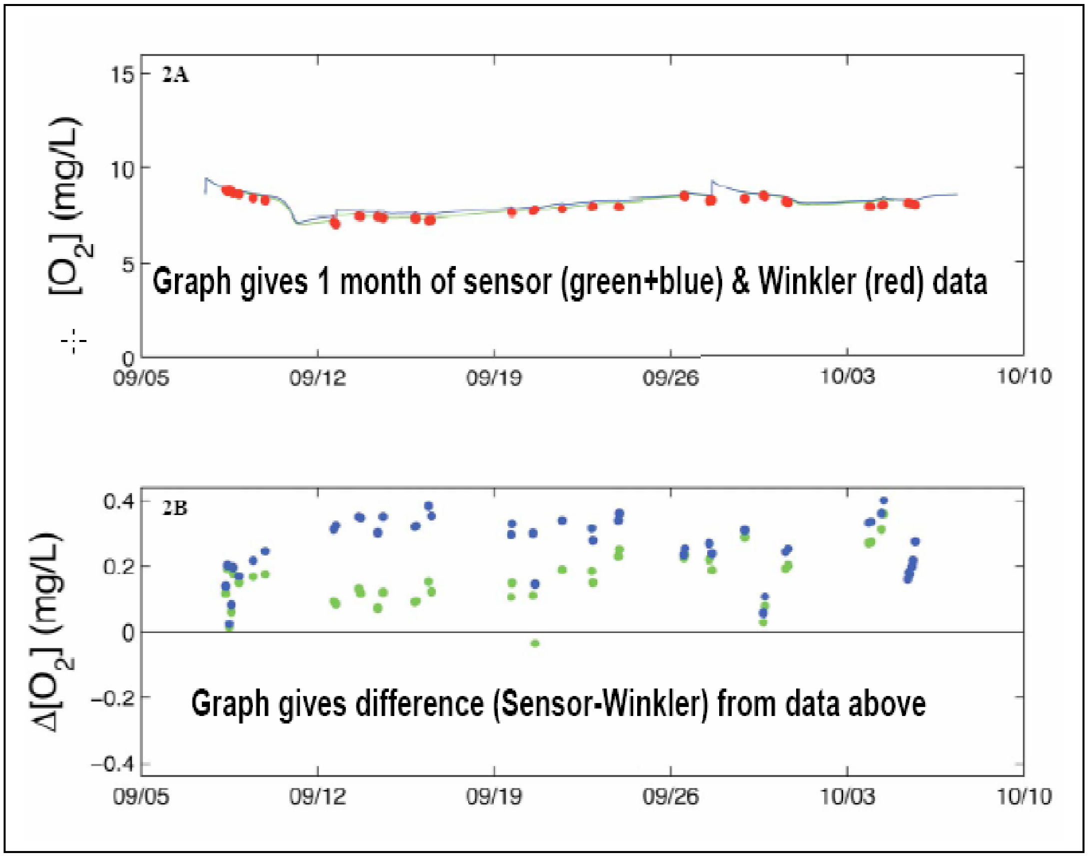

Figure 4

Sensor Performance in Anoxic Conditions
Optical DO sensors demonstrate a signal response that is inversely proportional to Dissolved Oxygen levels, e.g. longer luminescence = lower DO concentrations, shorter luminescence = higher DO concentrations. This allows optical sensors to exhibit superior performance in low DO concentrations—as this is near the full-scale response of the sensor.

In an internal experiment, the powerful oxygen scavenger sodium sulfite was repeatedly added to a sample of water to demonstrate the rapid and reproducible response of the Optical DO sensor to low oxygen concentrations. The sulfite rapidly brought the dissolved oxygen concentration in the water down to a virtually zero level. Air was continuously bubbled into the water sample, which consumed the sulfite. When the scavenger was eventually exhausted the dissolved oxygen content would rise back to saturation levels; sulfite was added once again to repeat the cycle. (Figure 5)

A primary application of oxygen monitoring in surface waters is protection of aquatic life against hypoxic conditions. A significant limitation of the Clark electrochemical cell is reduced accuracy and repeatability in this situation - however this is where the optical fluorescence oxygen detector operates at peak efficiency.

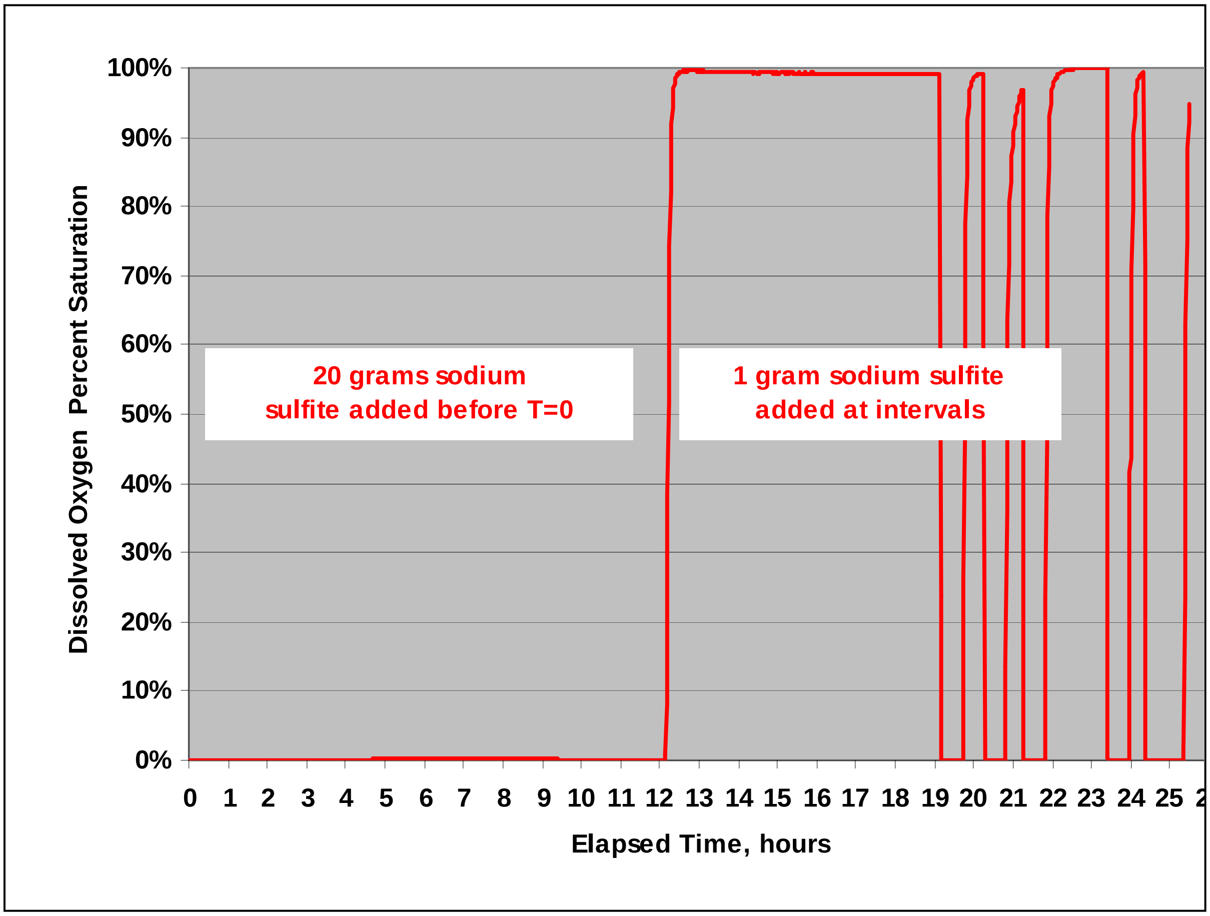

Figure 5

Conclusions and Summary

Optical Dissolved Oxygen Sensors present a breakthrough monitoring technology to a market that has seen little to no innovation for many years. While Clark Cell DO sensors have been in service for over 50 years and can provide fairly accurate data when properly maintained and calibrated, newer optical sensing technologies offer higher performance levels while eliminating many problems inherent to the older Clark cell sensor.

Optical DO sensors do not consume oxygen as part of an electrochemical reaction, and do not require sample flow for accurate readings. Optical DO sensors have no membrane or electrolyte and calibration is recommended just once per year. If sensors do become fouled or dirty, only a simple cleaning with a cloth or cotton swab is required prior to redeployment. When deploying instruments, Optical sensors do not require any warm-up period or long equilibration time to achieve their stated accuracy specifications. The measuring component of the sensor is long-lived—in some cases requiring replacement only once every 5 years. Sensors exhibit a fast response to changing DO levels, and show minimal drift over time—eliminating the need for frequent calibration. When researchers are attempting to characterize nutrient-related anoxia in open bodies of water, traditional sensing methodologies do not offer nearly the accuracy or precision required in this challenging environment.

Optical sensors have been proven in multiple field studies to give accurate data over short or long deployment periods—with minimal maintenance and calibration requirements. Manpower and material costs are drastically reduced, required site visits are minimized, and potential for user error is all but eliminated. Original ACT reports are located at: www.act-us.info

[1]State of Technology in the Development and Application of Dissolved Oxygen Sensors, Alliance for Coast Technologies (ACT) Workshop Proceedings, Savannah, Georgia, January 2004; University of Maryland Technical Report series No. TS-444-04-CBL, p.2.

[2]State of Technology in the Development and Application of Dissolved Oxygen Sensors, Alliance for Coast Technologies (ACT) Workshop Proceedings, Savannah, Georgia, January 2004; University of Maryland Technical Report series No. TS-444-04-CBL, p.1.

A MULTIDISCIPLINARY FRAMEWORK FOR PRIORITIZING FRESHWATER LAKE CONSERVATION IN LATIN AMERICA USING GIS

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KEY WORDS: lake conservation, freshwater, development, GIS, sustainable management

ABSTRACT

The need for freshwater conservation has increased dramatically over the past few decades as threats to biodiversity have intensified and water scarcity has continued to spread. The need for integrated water management is stronger than ever. Unfortunately, the lack of sufficient funding limits our ability to respond to all water problems; hence a framework for prioritizing conservation efforts is immensely needed. Water provides extremely valuable goods and services to ecological and human communities. It is critical for survival, yet it is a limited resource. Threats imposed on water resources are numerous, including water pollution, over extraction, water diversions and ecosystem degradation. In order to prioritize our conservation needs, a consistent framework is required. Current frameworks tend to isolate individual values of water rather than integrating them. Ideally, all conservation would focus on biodiversity; however, with pressures of population growth, increased agricultural demand and increased environmental stress, freshwater conservation must consider all dimensions including basic human needs. This paper proposes a multidisciplinary framework that combines existing measures of biodiversity, population growth, human development, food production and sustainability to determine priorities lakes for conservation. Geographic Information Systems (GIS) are used to integrate multiple databases and generate three different scenario-based frameworks for prioritization. The Latin America region is used to illustrate the dimensions of this analysis and to suggest appropriate databases for assessment. One of the three proposed frameworks is discussed in greater detail to illustrate the GIS prioritization process.

INTRODUCTION

Approximately ninety percent of the world's liquid surface freshwater can be found in lakes; nevertheless, lakes are being degraded at an alarming rate. Despite global degradation of freshwater, historically more conservation attention has been given to terrestrial issues such as the protection of tropical and sub-tropical forests (Castro & Locker 2000). Although environmental conservation may in fact be secular, terrestrial and freshwater issues are very much interconnected (Olson et al. 1998). Latin America harbors the richest freshwater biodiversity in the world but it also faces some of the most extreme challenges spawning from unsustainable economic development and poor management practices. As a result, lakes that provide an important source of water for community drinking, irrigation and fish protein have been neglected and abused (Seckler et al. 1998, Hansen & van Afferden 2001, Monetenegro-Guillen 2003). Integrated analyses of the long-term impacts of population and economic growth in Latin America are scarce. Support for unconditional economic growth has weakened efforts to manage resources sustainably. Freshwater lakes in particular have been largely overlooked by conservationists despite their critical value to human and wildlife communities. In most cases protection or restoration of biodiversity alone is the primary motivation for lake conservation. While lakes provide critical habitat for a wide range of biodiversity they are also imperative to support growing human populations dependent on them for drinking water, food production, transportation, energy, waste disposal and recreation. To date, not enough attention has been given to promote sustainable use of lake resources, thus lakes are deteriorating at a rapid pace. The root of these problems is simple and complex at the same time. The lack of economic and social stability throughout Latin America has contributed greatly to the degradation of lake resources, including biodiversity (Bucher et al. 1996, Groombridge & Jenkins 1998); the triangular issue of wealth, poverty and inequity is one of the leading drivers of biodiversity loss (Snel et al. 2004). Thus, as long as freshwater conservationists focus solely on protecting biodiversity, many lakes will continue to be damaged past the point of recovery. The impacts of continued degradation and exploitation will ensure a major loss of local and regional biodiversity and severely impact the social and economic health of the human communities that are intimately linked to lakes.

Attempts to assess the condition of lake ecosystems tend to be limited in scope, with emphasis on only one or two factors that affect lakes and freshwater resources. This study uses published research that has evaluated lake degradation as a result of unsustainable development in order to assess the threats to biodiversity and overall the sustainability of lake resources. In general, lakes are threatened by the degradation of water quantity and quality that results from the inadequate management of limited freshwater resources. Pollution (point and non-point), water diversion, and increasing human demand due to population growth and inadequate management pose the strongest threats to the sustainable use of lake resources (Bucher et al. 1996). Despite a wide array of research efforts that examine the economic and social development of Latin America, there are few if any that integrate evaluations of ecological services and biodiversity.

This paper attempts to bridge the gap between the development and conservation of freshwater in Latin America. The following countries were included in this analysis: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, French Guiana, Grenada, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay and Venezuela. By integrating prior regional freshwater biodiversity assessments with existing development-related statistics, this study uses Geographic Information Systems (GIS) to develop a framework for prioritizing freshwater lake conservation throughout the region. The information used in this analysis ranges from broad national statistics down to more specific ecoregional and watershed-level data. Recognizing the strengths and weakness of available data related to freshwater in Latin America, this analysis produced three different methodologies for determining priorities. The goal is to use existing information in the most effective manner; therefore, it combines more specific studies with broader national and regional reviews lending greater breadth and depth to the analysis. Indicators of economic development, human development, environmental sustainability and biodiversity are brought together to determine lakes within Latin America that should receive priority for conservation action.

METHODS

Several organizations and institutions have worked towards identifying freshwater biodiversity hotspots. The United Nations Environment Programme, LakeNet, the World Conservation Monitoring Centre, Ramsar, and World Wildlife Fund have all participated in studies that take an initial step towards identifying regions of biological importance (Olson & Dinerstein 1998, Olson et al. 1998, Groombridge & Jenkins 1998, Abel et al. 2000, Castro & Locker 2000, Castro & Parcels 2000, Duker & Borre 2001). The Food and Agriculture Organization, Population Action International, the CIA, and the "Health in the Americas" assessment (1998) have contributed valuable economic and human development reports (PAHO & WHO 1998, Gardner-Outlaw & Engelman 2000, WHO 2000, FAO 2002, CIA 2003, RAMSAR 2003). Table 1 provides a list of possible assessments that are suggested for this type of integrated analysis. Detailed explanations of each assessment can be found in the original reports as listed in the references section of this paper or in a more in-depth version of this paper (contact author).

Table 1. Development and biodiversity assessments included in analysis

Development Assessments	Biodiversity Assessments
Environmental Sustainability Index	WWF Freshwater Biodiversity Assessment
FAO - Irrigation	LakeNet 250 Lake Biodiversity Conservation Priorities
"Health in the Americas" - Sewage and Sanitation Coverage	World Conservation Monitoring Centre Biodiversity Assessment
Water Stress & Scarcity Assessment	Ramsar Site Designations
FAO Forest Loss/ WWF Terrestrial Ecoregions - Habitat Loss*	FAO Forest Loss/ WWF Terrestrial Ecoregions - Habitat Loss*
* The FAO Forest Loss and WWF Habitat Loss Assessments can be used interchangeably as biodiversity or development indicators due to the nature of the assessments.	

The results of these studies are cumbersome; therefore a spatial and attribute analysis has been conducted using Geographic Information Systems (GIS). The utilization of Geographic Information Systems in environmental conservation is not new (Dinerstein et al. 1995, Ricketts et al. 1999, Abel et al. 2000, Castro & Locker 2000, Castro & Parcels 2000). GIS layers corresponding to the development and biodiversity assessments listed above have been created and projected together geographically. Early stages of this study determined that using all the layers at once would not be the most efficient or illustrative method for two main reasons. First of all, by simultaneously projecting all layers, the analysis would assume that each layer carried equal weight or importance. While using GIS is an attempt to maintain crucial objectivity, placing equal weight on each layer is potentially misleading due to the uncertainty and incompleteness of the information available for water resources. Second, several of these assessments are compilations of many data categories; therefore certain combinations may be repetitive and sway the results. The Freshwater Ecoregion Priorities for Conservation Action assessment (Castro & Parcels 2000) and the Environmental Sustainability Index (ESI 2002) are two examples of such compilations. Careful consideration is needed when choosing the appropriate layers to include in any of these analyses. Three separate GIS analyses were produced in this study. Each analysis, or framework, is essentially a different combination of social, economic and ecological data found in previous assessments. The results of each analysis were subsequently scrutinized to validate findings.

RESULTS

The following combinations were found to highlight regions with strong threats to biodiversity *and* human development.

- Freshwater Ecoregion Status and LakeNet Biodiversity Conservation Priorities (Map A)
- Environmental Sustainability Index, Freshwater Ecoregion Priorities for Conservation Action, LakeNet Biodiversity Conservation Priorities, Rural Sewage and Sanitation Coverage, and Irrigation Distribution (Map B)
- Freshwater Ecoregion Priorities for Conservation Action and Terrestrial Ecoregion Conservation Status.

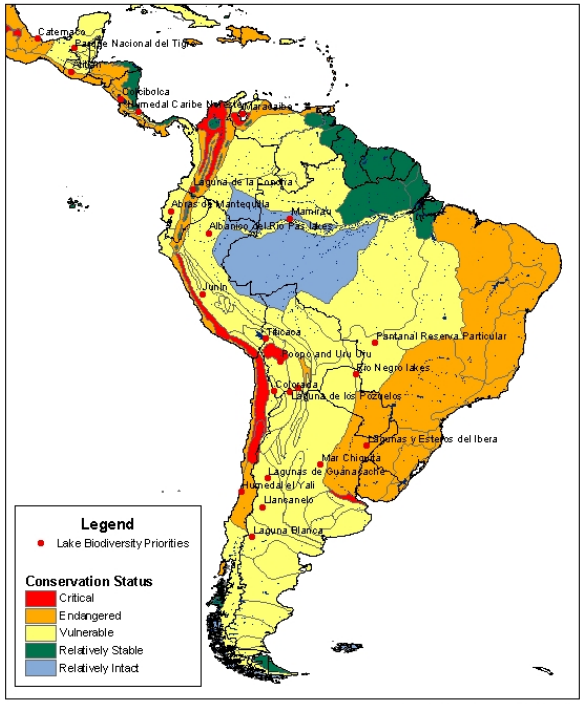
The second combination of data layers produced a well-balanced analysis of development and biodiversity assessments. By simultaneously projecting the Environmental Sustainability Index, Freshwater Ecoregion Priorities for Conservation Action, LakeNet Biodiversity Conservation Priorities, Rural Sewage and Sanitation Coverage, and Irrigation Distribution this analysis indicated that lake basins including Lake Cocibolca (Nicaragua), Lake Titicaca (Bolivia and Peru), Pastaza River Lake Complex (Peru), Lakes Peten Itza, Atitlan and lakes within el Parque Nacional del Tigre (Guatemala), Lakes Chapala, Catemaco, Tames, Corte Machona, Malpaso, and Angostura (Mexico), Lakes Calefquem, Lianquihui, Ranco, Rupanco, Toro, Todos los Santos, Villarrica, Yelcho, Rinihue, and Sarmiento (Chile), Lakes Juparana, Pentecoste, Araruaama, Feia and hundreds of smaller lakes and reservoirs (Brazil) deserve priority conservation efforts. Once these lakes were identified using the produced map, each region was investigated further to validate the findings. For example, Lake Chapala is the largest lake in Mexico and provides potable water for Guadalajara, irrigation throughout the watershed, and critical habitat to support economically important fishes and other wildlife. Unsustainable growth within the basin has contributed to falling lake levels and increased pollution. There have been at least eleven dams constructed upstream from Lake Chapala, leaving natural flows to the lake critically low. Water is diverted to provide for irrigation and drinking water to Guadalajara and Mexico City. Approximately 81% of Lake Chapala’s catchment basin is occupied by agriculture and irrigation coverage has quintupled over the past fifty years. Since the 1970s, lake volume has reduced more than half from 8.3 billion to 4 billion cubic meters. Before a considerable rainfall event during the fall of 2003, lake volume had plunged to only 1.2 billion cubic meters; 3.3 billion cubic meters is considered to be the critical point (). The loss of water from the lake is one major component of biodiversity loss, but in addition, pollution has skyrocketed as a result of poor water treatment practices. Other lakes, like Lake Titicaca in Peru and Bolivia, share similar life histories. In Figure 3, the ESI rank, Priorities for Conservation Action (PFCA), Percent Rural Sanitation Coverage and LakeNet Biodiversity Conservation Priorities have been projected together. The region surrounding Lake Titicaca is identified as the highest PFCA, moderately vulnerable according to the ESI cluster analysis and crossing nations with 23% (Peru) and 39% (Bolivia) rural sanitation coverage.

Discussion

Throughout the course of this paper several aspects of freshwater conservation have been discussed. First and foremost, this paper strongly suggested that freshwater conservation lacks the financial and research support that is needed in order to prevent or ameliorate existing degradation. Through the development of this analysis it has become increasingly obvious that water-related problems are intimately linked with economic development, land use and human development. In areas that lack proper wastewater treatment or sewage systems, nutrient pollution is high and water quality degraded. Similarly, regions of Latin America that are heavily populated experience greater water competition resulting in increased water diversion and unsustainable practices (Hansen & van Afferden 2001). The problem is circular and unless strong management and conservation practices are implemented where necessary, the situation will not improve. Thus, a consistent and reliable method of prioritizing freshwater conservation efforts is desperately needed, not only in Latin America but also all over the globe. The purpose of this multidisciplinary analysis has been to develop a framework for prioritizing conservation efforts in order to achieve the most effective means of preserving lake systems. While all lakes are intrinsically beautiful and deserve protection, the reality of limited financial resources proves to be an overwhelming adversary.

This study has suggested three approaches to prioritizing efforts using GIS. Not all are equally successful at identifying priority lakes; nevertheless, each offers a different outlook based on both biodiversity and development perspectives. Ultimately, the appropriate analysis must be developed specifically for each region. Overall, the critical component is to consider biodiversity conservation, economic development and human development simultaneously. Geographic Information Systems greatly facilitate this integration process. By examining several sets of data at one time, GIS tools can quickly determine regions that share the need for priority conservation. Building the appropriate analysis requires consistent and reliable data, preferably at the ecoregion or watershed-level. A successful analysis also requires a careful balance of information equally representing ecological and human sustainability. The use of GIS is at the forefront of environmental conservation initiatives, both terrestrial and aquatic. Where possible, conservation and development organizations should employ these techniques to improve the cost efficiency and overall success of projects. Again, while this particular analysis used a specific set data sources, depending on the region more may be available and should be incorporated in subsequent analyses. It is also important to note that the results of such a GIS analysis should be validated by an in-depth investigation, as was done above for Lake Chapala.

Latin America Conservation Status
and Lake Biodiversity Conservation Priorities



Lehner & Doll (2003); Olson et al. (1998);
Duker, L. and L. Borre (2001); Base map: ESRI (2003)

ESI Cluster Analysis, Freshwater PFCA, Rural Sanitation
Coverage and Lake Biodiversity Conservation Priorities

Lehner & Doll (2003); Olson et al. (1998);
Duker, L. and L. Borre (2001); ESI (2002); PAHO & WHO (1998)
Base map: ESRI (2003)

Figures 1 & 2. GIS integrated analyses A & B

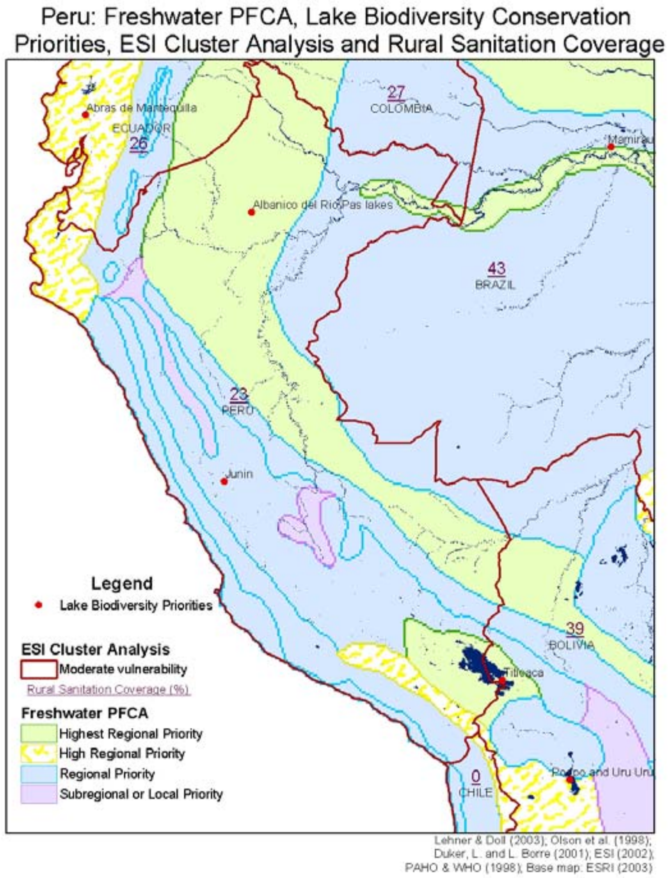


Figure 3. Integrated data map of Peru and Bolivia

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PREFERENCE ANALYSIS OF HOME PLUMBING MATERIAL

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KEY WORDS: AHP (Analytical Hierarchical Process), human preference, plumbing materials

ABSTRACT

About 90% of domestic drinking water plumbing systems in the USA use copper pipes. Recently, there has been a significant increase in pinhole leaks in these copper plumbing pipes. For majority of homeowners, their home is the most valuable asset. The possibility of falling home value and health concerns have caused considerable anxiety among the affected homeowners. There is a need for a decision tool for determining whether to continue to repair or replace the system and which material to use. Currently, PEX (Cross-linked polyethylene) and CPVC (Chlorinated Polyvinyl Chloride) are used along with copper. Stainless steel is being considered but does not have a significant market share. The material selection process is formalized within the frame work of the Analytic Hierarchy Process (AHP). Multiple attributes including price, corrosion resistance, fire retardance, health effects, longevity, re-sale value of home, and taste and odor are considered. The methodology was carried out with the help of a focus group of twelve participants.

INTRODUCTION

There is a noticeable increase of pinhole corrosion in copper plumbing pipes. Also, there is a concern regarding the behavior of plastic pipes (PEX, CPVC) with respect to strength, fire hazard, final disposal, reaction to chlorine and health effects. Stainless steel is considered less susceptible to corrosion. Its price is generally considered high for home plumbing compared to the other materials. According to Marshutz' survey (2000), copper accounts for 90% of new homes, followed by PEX (cross linked polyethylene) at 7%, and CPVC (chlorinated polyvinyl chloride) at 2%. Telephone surveys of plumbers tend to show an increased use of plastic pipes due to easier handling in installation and lower material cost. When building a new house or replacing an existing plumbing system, material choice involves cost (material cost plus labor and installation cost), health effects, water quality including microbial growth, corrosion susceptibility, strength, consumer preference from the point of view of selling the house, and behavior in the case of a fire. Figure 1 contains the factors to be considered.

Analytical Hierarchy Process (AHP)

The material selection process is formalized with the aid of the AHP (Analytical Hierarchy Process). The AHP is a procedure for assessing preferences over a set of competing alternatives by using pair-wise preferences. It is generally taken that assessing pair-wise preferences is easier as it enables to concentrate judgment on taking a pair of elements and compare them on a single property without thinking about other properties or elements [Saaty (1990)]. It is noted that elicited preferences may be based on the standards already established in memory through a person's experience or education. All rely heavily on measurements and tradeoffs of intangibles in a multi-criteria process. Based on Saaty (1980) the following steps are adopted in performing the analytical hierarchy process.

Firstly, a set of attributes is identified. For plumbing material selection the following seven attributes are considered. Price—includes cost of materials and labor for installation and repair; Longevity—length of time material remains functional; Reliability—dependability of material to remain free of leaks and other forms of pipe failure; Fire retardance—ability of material to remain functional at high temperatures and not to cause additional dangers such as toxic fumes; Water taste and odor—ability of material to deliver water without imparting odor or taste; Health effects—ability of material to remain inert in delivering water without threatening human health; and Effects on property value—people's preference for a particular material including aesthetics (see Figure 1).

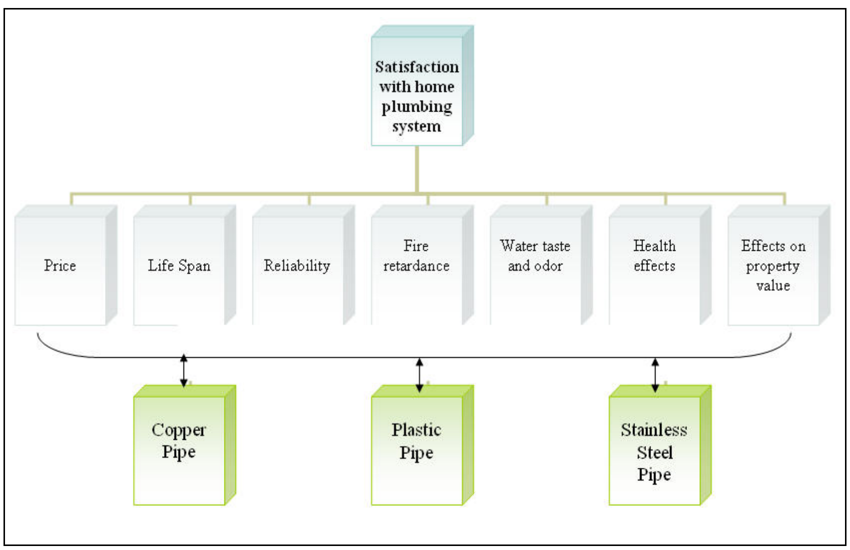

Figure 1. Plumbing Material Selection

Secondly, a scale of pair-wise preference weights is set as given in Table 1. The usual scale ranges from 1 – 9. For the present analysis a 1-7 scale is adopted as shown in the last column of Table 1 (see p.56 Saaty, 1980).

Table 1. Standard numerical scores

Preference Level	Numerical score, a(i,j) 1-7 scale
Equally preferred	**1**
Equally to moderately preferred	**2**
Moderately preferred	**3**
Moderately to strongly preferred	**4**
Strongly preferred	**5**
Strongly to very strongly preferred	**6**
Very strongly preferred	**6**
Very strongly to extremely preferred	**7**
Extremely preferred	**7**

Thirdly, each participant is asked to fill in a 7x7 attribute matrix of pair-wise preferential weights as shown in Table 2.

Table 2 is a reciprocal matrix in that the off diagonal elements are reciprocals of each other. In row H and column P, the entry of 7 implies that health effects are extremely important in comparison to price. In row R and column V, the cell value of 3 indicates reliability is moderately preferred over the value of home.

Table 2. Pairwise preference weight matrix

Attribute	P	L	R	F	T	V	H
P	1	0.33	0.2	0.2	0.2	1	0.143
L	3	1	1	1	0.33	1	0.143
R	5	1	1	1	0.2	3	0.143
F	5	1	1	1	0.2	1	0.143
T	5	3	5	5	1	3	0.333
V	1	1	0.33	1	0.33	1	0.2
H	7	7	7	7	3	5	1
Sum	27	14.3	15.5	16.2	5.27	15	2.1

(P: price, L: life span, R: reliability, F: fire resistance, T: taste & odor, V: property value, and H: health effects)

Fourthly, rescaled preference matrix is generated by dividing each column entry in Table 2 by that column's sum yielding Table 3. The last column "Average" contains average values for each row and shows the ranking of the attributes. Table 4 shows the ordered relative ranking of the attributes.

Table 3. Rescaled pairwise weight matrix

Attribute	P	L	R	F	T	V	H	Average
P	0.04	0.02	0.01	0.01	0.04	0.07	0.07	0.04
L	0.11	0.07	0.06	0.06	0.06	0.07	0.07	0.07
R	0.19	0.07	0.06	0.06	0.04	0.2	0.07	0.10
F	0.19	0.07	0.06	0.06	0.04	0.07	0.07	0.08
T	0.19	0.21	0.32	0.31	0.19	0.2	0.16	0.22
V	0.04	0.07	0.02	0.06	0.06	0.07	0.1	0.06
H	0.26	0.49	0.45	0.43	0.57	0.33	0.48	0.43
Sum	1	1	1	1	1	1	1	1

Table 4. Relative ranking of attributes

Attribute	Weight
Health Effects	0.43
Taste and Odor	0.22
Reliability	0.10
Fire resistance	0.08
Longevity	0.07
Property Value	0.06
Price	0.04

RESULTS

Table 5 contains the attribute ranking for all 12- participants. From Table 5, it is clear that participants rank the health effects the highest, followed by reliability, taste and odor and longevity; price, property value and fire resistance are at the bottom of the list. These results show that health, and taste and odor again may be a surrogate for the purity of water dominate preferences for a plumbing material. Reliability is related to mental tress. Public are very concerned about ripping the dry wall to replace a failed pipe without a guarantee that another leak will not spring in the future. The writers are continuing their research to link material properties with the attribute ranking to obtain a ranking of available plumbing pipe materials.

Table 5. Participant ranking of attributes

Participant/ Attribute	S	P1	J	E	D	P2	A	J2	R	A2	T	A3
P	0.06	0.10	0.11	0.03	0.06	0.17	0.04	0.09	0.13	0.04	0.08	0.04
L	0.18	0.21	0.13	0.08	0.16	0.17	0.07	0.12	0.12	0.13	0.15	0.24
R	0.18	0.20	0.15	0.17	0.11	0.17	0.10	0.17	0.09	0.17	0.10	0.14
F	0.08	0.02	0.04	0.07	0.03	0.05	0.08	0.02	0.06	0.05	0.02	0.08
T	0.03	0.07	0.17	0.14	0.20	0.06	0.22	0.07	0.03	0.25	0.19	0.12
V	0.04	0.04	0.05	0.03	0.06	0.02	0.06	0.06	0.16	0.02	0.06	0.07
H	0.43	0.36	0.35	0.47	0.38	0.36	0.43	0.46	0.40	0.33	0.39	0.32

(P: price, L: life span, R: reliability, F: fire resistance, T: taste & odor, V: property value, and H: health effects)

ACKNOWLEDGEMENT

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MARKOV MODELING OF ENSO AND CONDITIONAL RESPONSES OF SOUTHWEST VIRGINIA PRECIPITATION TO EL NINO

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KEY WORDS: El Nino, Southern Oscillation, Weather patterns, Precipitation

ABSTRACT

In this paper, a combination of large scale weather patterns with local weather fluctuations is considered for analyzing correlation between station level precipitation values. The resulting correlations and frequency patterns suggest that improvements in forecasts are possible. The El Nino events are analyzed with the aid of Troup Southern Oscillation Index in a Markov Chain framework. Mean recurrence times and uninterrupted residence times are reported.

INTRODUCTION

It has become common to model precipitation variation and occurrence in the southeastern United States using large scale circulations including the El Nino-Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), and Pacific North American (PNA) pattern (Tebaldi 2000, Katz et al. 2003). Studies by (El-Askary et al. 2003) and (Knocke et al. 2005), which proposed a viable relation between precipitation variation in Virginia and ENSO, helped to initiate both phases of this work. First, non-homogeneous and homogeneous Markov Chain models are implemented on a monthly time series of the Troup Southern Oscillation Index (SOI) as a means to gain transitional and long-term steady state behavior as well as uninterrupted residence and recurrence durations for the three phases of ENSO.

Secondly, this work assesses the responses of daily southwest Virginia precipitation for concurrent occurrence of El Nino and each of the seven daily weather patterns designated by Sheridan's Synoptic Classification Scheme (SSC). Daily weather type frequency distributions in southwest Virginia, conditional on the El Nino event, are additionally realized.

METHODS

Monthly SOI data was obtained from the Australian Bureau of Meteorology (BOM) webpage <http://www.bom.gov.au/climate/current/soihtm1.shtml> from 1876 through 2004. See documentation linked to this site and (D'Aleo 2002) for SOI and ENSO details. It is pertinent to note that the SOI represents the monthly standardized mean sea level pressure difference between Tahiti in the central tropical Pacific Ocean and Darwin, Australia in the western tropical Pacific. During El Nino, relative changes in sea level pressure at these locations induce negative SOI values. The original SOI data was transferred into a 3-month moving series given the acknowledged high month to month variation typical of pressure indices (Lohani 1995).

Concerning the Markov-related work, augmenting the reported SOI data into severity classes renders the index as a random variable and produces a time series defined as a discrete-time stochastic process, assumed to follow the Markov property (Isaacson, 6). Seven severity classes were arbitrarily chosen to give adequate resolution to the monthly series, while boundary values used to define each class followed guidance offered by (Sen et al. 2004) and (Yue 2001) for the Troup SOI.

Table 1. Troup Southern Oscillation Index (SOI) Severity Class Assignment

Class	SOI Interval	ENSO Phase
1	-20 or less	Strong El Nino
2	-19.999 to -10	Moderate El Nino
3	-9.999 to -5	Weak El Nino
4	-4.999 to 4.999	Neutral
5	5 to 9.999	Weak La Nina
6	10 to 19.999	Moderate La Nina
7	20 or more	Strong La Nina

Monthly evolution of the SOI can be captured by transition probabilities corresponding to the non-homogeneous chain and are computed as:

$$p_{i,j}^{(n,n+1)} = P[SOIclass_{n+1} = j|SOIclass_n = i] = N_{i,j}^{(n,n+1)} / N_i^{(n)} \qquad (1)$$

where $N_{i,j}^{(n,n+1)}$ = number of occurrences where the SOI class moved from i in month n to j in month n+1; $N_i^{(n)}$ = number of occasions where class i was present during month n. (Lohani and Loganathan 1997). When monthly transition probabilities are dependent on the time at which the step is made, the process is non-homogeneous. A matrix for each monthly transition (eg. January to February) compile these transition probabilities for i,j = 1, 2, …7, as is shown in Table 2 for the June to July transition.

Offered by the non-homogeneous chain is estimation of uninterrupted mean residence of each SOI class through the following conditional solution:

$$E[R_i \mid startingmonth] = \sum_{k=1}^{k_{\max}} k * P[m = k \mid startingmonth] \qquad (2)$$

as R_i = uninterrupted residence of class i as a random variable conditioned on the month at which class i is first observed, k = the range (number of months) over which R_i is defined, and m = residence time (months). Residence results for each class, conditional on the month at which it first appears, are provided in Table 3.

Homogeneity can be assumed for the SOI class series if its advancement is irrelevant to time (Isaacson, 7). Computation of the mean transitional probabilities belonging to the homogeneous, or stationary, chain is arrived at through equation (3):

$$p_{i,j} = (N_{i,j}/N_T) / (N_i/N_T) = N_{i,j} / N_i \tag{3}$$

in which $N_{i,j}$ = number of occasions where the chain encounters a one-step change from class i to class j, N_T = total number of data points in the record, and N_i = number of months in the record existing in class i (Lohani 1995). The mean monthly transitional matrix is the collection of $p_{i,j}$ for i,j = 1,2,…7 and showcases the stationary process. Steady state probability distributions are accessible for both the non-homogeneous with formulation (4). From (Isaacson, 1976), the SOI class distribution after k monthly transitions from the beginning month 1, $f^{(k)}$, of the non-homogeneous chain can be obtained with the following relation:

$$f^{(k)} = [f^{(0)}] [P_1] [P_2] \ldots [P_k] \tag{4}$$

by which $f^{(0)}$ is termed the initial index class probability row vector, and $[P_t]$ pertains to the transitional matrix between months t and (t+1) (Lohani, 1995). A similar expression is available for the homogeneous chain.

A relation for $f^{(k)}$ as $k \rightarrow \infty$ that is independent of the initial class row vector permits the steady state solution (Lohani, 1995). According to Isaacson, $f^{(0)}$ is forced out from these expressions if $[P_1] [P_2] \ldots [P_k]$ and $[P]^k$ equates to a constant stochastic matrix (1976), thus reducing equation (4) to:

$$f^{(k)} = \varphi^{(\text{month m, k})} = [P_m] [P_{m+1}] \ldots [P_k] \tag{5}$$

for starting month m, where $\varphi^{(\text{month m, k})}$ is deemed the composite matrix as reported by (Lohani and Loganathan, 1997). Each month's composite matrix for the non-homogeneous chain is computed, with a sample of the results reported in Table 4. The steady state class distribution for the stationary process is omitted here due to space constraints. Accompanying the non-homogeneous samples are the observed long term class probabilities for each month, arrived at through simply scanning the historical record; significant resemblance between these results aids confirmation of equation (5).

To capture periodic behavior of ENSO, mean recurrence times can be generated from the mean monthly transition matrix by taking the reciprocal of each homogeneous steady state class probability. These measures of frequency, accompanied by the stationary chain's steady class occurrence distribution can be found in Table 6.

Retrievable from Dr. Scott Sheridan's SSC homepage (http://sheridan.geog.kent.edu/ssc.html) is a calendar of weather for Roanoke, Virginia, where each day is compartmentalized into one of seven weather types describing the daily air mass over Roanoke. Seven weather types are identified by humidity, temperature, cloud cover, and typical source region, and possess the following designations: (1) Dry Polar (DP); (2) Dry Moderate (DM); (3) Dry Tropical (DT); (4) Moist Polar (MP); (5) Moist Moderate (MM); (6) Moist Tropical (MT); and (7) Transition (TR) (Sheridan 2002). These weather patterns differ from Bergeron's (1930) classification of cP, cT, mP, and mT in DM, MM, and TR.

This study uses Sheridan's series of daily Roanoke weather types and daily precipitation from stations at Bedford, Blacksburg, and Roanoke Airport from 1950-2003. Weather types for all stations are assumed to take on the sequence assigned for Roanoke. Missing entries in the weather type series were assigned the previous day's value, and daily precipitation data were removed for all stations if any of the three had a missing value. Providing the first stage of conditioning, El Nino occurrence was assumed for months when the 3-month moving mean Troup SOI was equal to or less than -5. Daily weather type sequences were scanned for months that met this El Nino condition, and data from the three precipitation stations were arranged into seven subsets corresponding to monthly El Nino and each weather type concurrence. Table 7 shows the number of days [from filtered data] during El Nino months where each weather type was observed – the notation "EN_SSC 1" reflect days during El Nino months of DP weather. Also shown here is daily average precipitation and standard deviation for each station, for each of the seven conditions. Precipitation data is then standardized using these statistics and spatial relations are evaluated through zero-lag correlations – see Table 7 for correlation results.

Frequency distributions of the standardized precipitation data are then acquired for each of the seven subsets of El Nino-weather type conditions; however, shown here are only distributions associated with the weather type of greatest incidence (EN_SSC 1) and that pertaining to high spatial correlations (EN_SSC 5) in Figures 1 and 2 respectively.

RESULTS AND DISCUSSION

Concerning transitional tendency of the non-homogeneous chain, Table 2 shows that if strong El Nino conditions have been observed in June, one-quarter of the time the tropical Pacific basin will move towards neutrality; in addition, the SOI exhibits the aptitude to discontinuously move from moderate La Nina, class 6, to neutral, class 4, during the June to July transition. Also noteworthy is the potential for class 2 to move into class 1 from the February thru May transitions, thereby strengthening an El Nino event, while all monthly transitions demonstrated elevated tendency for the process to attain the neutral class. Foremost when reviewing uninterrupted mean residence results offered in Table 3 is the conspicuous duration of class 7 if a strong warm pool appears in May in the western tropical Pacific. With a mean residence of 5 1/3 months, lower than normal atmospheric pressures can be predicted to persist in the western portion of the basin thereby sustaining high easterly trade winds as well as cold ocean and atmospheric temperatures in the eastern Pacific throughout the summer and into fall. Also evident is the pronounced escalation for class 1 residence if the corresponding strong El Nino state arises during November, December, or January.

These outcomes align with the southward displacement of the ITCZ near 8°S during winter, which, as Philander (1990) notes, is associated with the presence of El Nino.

Significant similarities exist between this enhanced winter residence and the deemed "mature" phase of El Nino defined for the winter months by (Wang 2002) in the year at which the peak of El Nino is attained. Moreover, the sudden rise of mean expected residence for both the pronounced El Nino and La Nina class from April to May is congruent with Wang's (2002) "development phase."

Table 2. June to July SOI Transition Matrix

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Class 1	0.7500	0.2500	0.0000	0.0000	0.0000	0.0000	0.0000
Class 2	0.0000	0.7333	0.2667	0.0000	0.0000	0.0000	0.0000
Class 3	0.0000	0.1111	0.3333	0.5556	0.0000	0.0000	0.0000
Class 4	0.0000	0.0000	0.0517	0.7586	0.1724	0.0172	0.0000
Class 5	0.0000	0.0000	0.0000	0.3333	0.4286	0.2381	0.0000
Class 6	0.0000	0.0000	0.0000	0.2727	0.0000	0.7273	0.0000
Class 7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table 3. SOI Mean Uninterrupted Residence Times (months)

Class 1	5.5480	4.5480	3.5480	2.5480	4.6441	3.6441	3.5255	3.7884	4.1826	4.7739	7.5480	6.5480
Class 2	2.8334	3.6667	3.4286	3.1572	3.5055	4.0087	4.1028	3.9490	3.1759	2.4177	2.3991	2.4167
Class 3	2.1149	1.8582	1.8724	1.8694	2.0286	1.6715	2.0146	1.8842	2.1000	1.8700	1.8366	1.9870
Class 4	4.3175	4.4748	4.1264	4.1460	3.8523	4.3133	4.3676	4.5857	4.7532	4.9433	4.8306	4.4265
Class 5	1.7964	1.6924	1.7806	1.8957	1.6285	1.8855	2.0662	2.0258	2.4363	2.0348	1.8815	2.0567
Class 6	3.1948	2.6338	2.3878	2.1351	2.9189	3.1982	3.0225	3.1461	4.6499	4.2583	4.1469	3.6310
Class 7	1.0000	1.0000	1.0000	1.0000	5.3333	4.3333	3.3333	2.3333	2.0000	1.5000	1.0000	1.0000
startmonth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Table 4. January Steady Class Occurrence Distribution

	Class1	Class2	Class3	Class4	Class5	Class6	Class7
Markov	0.007811	0.095813	0.15206	0.455202	0.132823	0.140661	0.01563
Observed	0.007813	0.09375	0.15625	0.453125	0.132813	0.140625	0.015625

Table 5. Recurrence and Homogeneous Steady Class Occurrence Distributions

	Class1	Class2	Class3	Class4	Class5	Class6	Class7
	0.01693	0.11791	0.13420	0.45277	0.14984	0.11922	0.00912
Recurrence (years)	4.92106	0.70674	0.62095	0.18405	0.55616	0.69899	9.13685

Table 6. Occurrence of Weather Type During El Nino Months & Daily Average Precipitation for Each Station and (Standard Deviation)

	EN_SSC 1	EN_SSC 2	EN_SSC 3	EN_SSC 4	EN_SSC 5	EN_SSC 6	EN_SSC 7
Occurrence (days)	1377	654	307	723	495	578	400
Bedford (inches*10^2)	4.36 (22.1)	2.76 (12.2)	2.00 (10.1)	26.36 (45.3)	23.57 (42.3)	11.61 (37.8)	24.69 (49.1)
Blacksburg (inches*10^2)	3.92 (18.1)	2.40 (8.82)	3.78 (20.17)	24.89 (38.69)	20.58 (32.7)	14.16 (31.8)	22.89 (41.2)
Roanoke (inches*10^2)	0.717 (4.78)	0.878 (4.94)	1.25 (8.02)	24.42 (52.6)	33.71 (51.9)	10.48 (29.7)	18.67 (38.5)

Table 7. Zero-Lag Correlation Coefficients Between Precipitation Gauge Stations for Each El Nino-Weather Type Condition

	EN_SSC 1	EN_SSC 2	EN_SSC 3	EN_SSC 4	EN_SSC 5	EN_SSC 6	EN_SSC 7
Bed-Bburg	0.729	0.504	0.326	0.609	0.668	0.535	0.712
Bed-Roa	0.051	0.03	0.342	0.338	0.367	0.211	0.483
Bburg-Roa	0.037	0.015	0.199	0.405	0.389	0.197	0.441

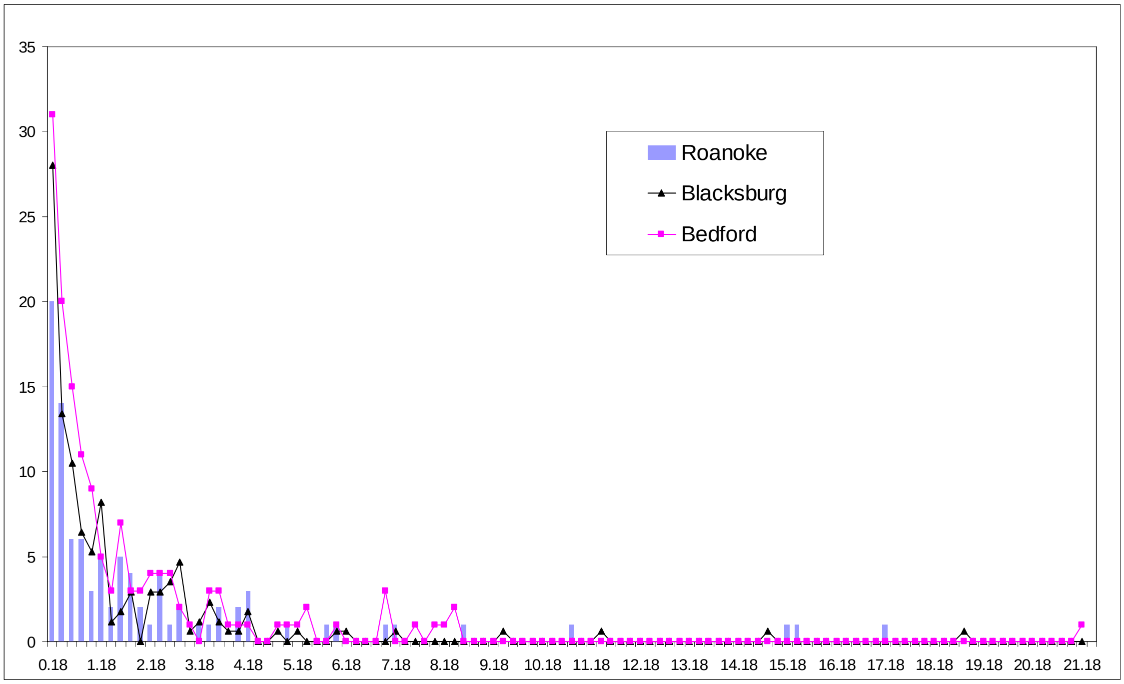

Figure 1. Frequency (days) vs. Standardized Precipitation for the EN_SSC 1 Condition

Figure 2. Frequency (days) vs. Standardized Precipitation for the EN_SSC 5 Condition

A valuable implication from the non-homogeneous steady state computations is La Nina's raised occurrence during winter months (DJF), as supported by Table 4. These findings complement D'Aleo's (2002) claim that La Nino episodes often initiate in winter. Furthermore, aggregating classes 1-3 and 5-7 for each month's steady class distribution show higher incidence of the El Nino phase from August through November.

A practical approach for analyzing mean recurrence results in Table 5 is to compute weighted averages for the El Nino and La Nina classes respectively given that an important feature of ENSO is its affinity to be in constant fluctuation about normal (Trenberth 2003). Weighted averages of 4 and 8 years for El Nino and La Nina are generated and align with higher positive ENSO occurrence in the historical record when evaluated against the negative phase (D'Aleo, 2002). NOAA's (http://www.pmel.noaa.gov/tao/elnino/nino-home.html) claim that La Nina can be anticipated to follow a percentage of El Nino events is maintained by the expectation for La Nina to follow every other El Nino event according to the 4 and 8 year recurrence results. Other works have shown El Nino to exhibit an average period of 3 to 7 years (Trenberth 2003), 3 to 4 years (Philander 1990), and 4 years (Sen et al. 2004; The National Academies, <www.nationacademies.org>), which corresponds well with this study.

Applying the El Nino condition to Sheridan's SSC daily weather type series proved that the Dry Polar air mass is most often (Table 6) positioned over Roanoke during months where easterly trade winds relax; therefore, the Roanoke region has most often encountered northerly winds given DP's source region is typically a cold anticyclone in Canada (Sheridan 2002). Escalated incidence of Moist Polar, MP, was also apparent for southwest Virginia during El Nino conditions, which corresponds well with its typical source region being the North Pacific or North Atlantic. In fact, (Sheridan 2002) states that the MP air mass is often DP air that has gained moisture through convection of inland surface waters, predominately the Great Lakes.

Daily averages for El Nino months, computed for all seven subsets of the precipitation data show that Bedford and Blacksburg can expect their relative highest mean daily precipitation for the Moist Polar condition, while Roanoke may endure relatively wet weather when El Nino unites with the Moist Moderate air mass. It may also be expected that southwest Virginia does not have a dominant wet weather response to relaxed easterly trade winds in the tropical Pacific since the most common weather type during El Nino, DP, corresponds to low daily average precipitation.

Figure 1 shows that Bedford experiences wetter weather compared to Blacksburg and Roanoke during El Nino months for the DP air mass; however, Roanoke demonstrates higher frequency at the heavier precipitation portion of the distribution. Evident from Figure 2, wet conditions prevail at Bedford verses than the other stations for the El Nino-MM condition, although higher incidences of above average precipitation is common to all the stations when evaluated against El Nino-DP distribution.

Considerable spatial relations appearing in Table 7 between precipitation data at the three stations were found for the concurrence of El Nino and MP and MM. These results should direct future investigations into their causality.

Importantly, raised precipitation in the greater Roanoke area may be the effect of an El Nino event when pressure in the north Atlantic Ocean is sufficiently high to bring in Moist Polar air. Moreover, high variations (standard deviations in Table 6) computed on this subset may help elude to the complicated geographic features, namely the Appalachian mountains, that often "control" southwest Virginia weather (Myatt 2005). This potential relation of El Nino and the north Atlantic and Pacific oceans exposed by this study provides an excellent starting point for future work that will examine southwest Virginia precipitation response to varying combinations of ENSO, the North Atlantic Oscillation (NAO), and Pacific North American (PNA) pattern.

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MARYLAND HOME DRINKING WATER ASSESSMENT

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KEY WORDS: corrosion, home plumbing, consumer attitude, pinhole leaks

ABSTRACT

Pinhole leaks commonly occur in copper pipes due to small holes caused by pitting corrosion of water pipes. While pinhole leaks are a nationwide problem, they have been reported more frequently in certain localities. The objectives of this research are 1) to evaluate the frequency and potential causal factors associated with pinhole leaks in home plumbing; 2) to evaluate the relationship between pinhole leaks and consumers' perceptions of water quality; and 3) to assess the financial and time costs incurred by consumers and their home insurers in repairing damages to plumbing and property resulting from pinhole leaks. A mail survey of Maryland residents in the suburbs of Washington, D.C. was conducted in July 2004. The purpose of the survey was to provide information on consumers' attitudes and experiences related to drinking water and their home plumbing systems. The survey provided information on the incidence of pinhole leaks and associated costs. This area was selected because of previous proactive efforts of the Washington Suburban Sanitary Commission (WSSC) in tracking leaks (WSSC, 2004). The total sample size was 5,013 with 3,000 surveys (60%) sent to households in three zip codes where the greatest number of leaks had been reported. The remaining surveys were sent to residents in other zip codes where leaks were also reported to WSSC. A total of 1,128 responses were received for a total margin of error of about 3%. This paper reports on survey results.

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INTRODUCTION

Pinhole leaks commonly occur in copper pipes due to small holes caused by pitting corrosion of water pipes. Pitting corrosion is pipe corrosion concentrated on a very small area of an inner pipe. Theories on what causes pinhole leak incidents vary and there may be several causes (Edwards et al. 2004). Edwards (cited in Dalton, 2003) suggests that removal of natural organic matter mandated by tighter Environmental Protection Agency (EPA) drinking water standards contributes to the problem. Natural organic matter may be a buffer against corrosion-inducing chemical reactions. Pipe failures can also be a result of aging piping systems and improper water pipe installation. For example, the copper lining of a water pipe might be wearing off due to friction of the pipe against an inner wall where it is located (Fleishman, 2001).

In most cases, the pinhole leaks are hard to detect, especially, if they appear in pipes running through walls and ceilings. If they are visible, they emerge as a green wet area on pipe and porcelain fixtures. Additionally, sediment buildup in toilet tanks and a persistent strong smell of chlorine in the water supply are noticeable. The damage from pinhole leaks includes collapse of walls and ceilings, as well as ruined support studs and floor coverings. Generally, it is recommended that pipes be replaced after three or four leaks (Gurner, 2003).

Pinhole leaks may also lead to creation of mold on the surface of walls, floors, and ceilings, which is very hazardous to human health. Mold exposure can cause allergic reaction such as irritation of eyes, skin, nose, throat, and lungs, and sometimes can create a burning sensation in these areas. Furthermore, copper itself can cause severe health problems such as liver and kidney failure, if consumed in doses higher than 1.3 mg/l (EPA, 1992). While pinhole leaks are a nationwide problem, they appear to be more common on the East Coast especially in the greater area of Washington, D.C., including the Virginia and Maryland suburbs. Problems have also been reported in Tennessee, Florida, Ohio, Massachusetts, Maine, and South Carolina. Some states such as Florida have actually banned copper piping from use to control the rising number of incidents (Gurner. 2003).

The objectives of this research are 1) to evaluate the frequency and potential causal factors associated with pinhole leaks in home plumbing; 2) to evaluate the relationship between pinhole leaks and consumers' perceptions of water quality; and 3) to assess the financial and time costs incurred by consumers and their home insurers in repairing damages to plumbing and property resulting from pinhole leaks.

METHODS

A mail survey of Maryland residents located in the greater Washington, D.C. area was conducted in July 2004. The purpose of the survey was to provide information on consumers' attitudes and experiences related to drinking water and their home plumbing systems. The survey provided information on the incidence of pinhole leaks and associated costs. This area was selected because of the large number of pinhole leaks reported by utility customers to the Washington Suburban Sanitary Commission (WSSC, 2004). A stratified random sample of 5,015 residents in the zip codes served by WSSC was chosen. Zip codes with high incidence of reported leaks to the WSSC and zip codes containing water treatment plant were sampled more heavily. The survey was distributed following the Dillman technique of mail surveying, which included mailing a questionnaire with postage-paid return envelope, sending a reminder card, and sending a second copy of the survey to nonresponders.

The sample design was intended to fulfill two purposes[2]: 1) provide a gauge of the incidence of corrosion and pinhole leak problems across the study area (Maryland suburbs of Washington D.C.); and 2) target areas with high reported rates of pinhole leaks in order to provide more information about this group. Due to financial constraints of the project, the sample consisted approximately of 5,000 households with 3,000 surveys allocated to zip codes located near the Patuxent and Potomac water plants. The remaining 2,000 surveys were distributed to the other zip codes reporting leaks in the WSSC database. These surveys were distributed based on the proportion of reported leaks in the zip code area relative to the total number of leaks in the remaining area. A minimum of 10 surveys was sent to every zip code reporting leaks.

The survey results provide information on the type and age of residence, and whether or not a leak has occurred. Survey data also provide information on respondents' perceptions of drinking water quality in their homes. For responders reporting leaks, information is reported on location and number of leaks and estimated financial costs as well as the amount of time spent by consumers in repairing leaks and resulting property damage.

SURVEY RESULTS

Pinhole Leak Incidents

A total of 1,128 responses were received for a total margin of error of about 3%. One hundred and six responses were dropped from the analysis because responses were incomplete. The following analysis is based on the remaining 1,022 responses. Three hundred sixty-six respondents (36%) reported incidents of pinhole leaks in copper pipes; 475 respondents (46%) reported no incidents of pinhole leaks; and 181 respondents were not sure of any incidents. The 366 respondents with pinhole leaks in copper pipe represented 47% of respondents with copper pipes in their home plumbing. The rate of leaks among the population may be lower if those who did not respond to the survey have fewer leaks than reported in this sample. Three heavily sampled zip codes accounted for 62% of total usable responses and 69% of respondents reporting pinhole leaks.

Forty-five percent of households with leaks had 1 or 2 pinhole leaks requiring a repair, 24% had 3 or 4 leaks, 12% had 5 or 6, and 17% had 7 or more incidents. Forty-six percent of respondents reported that the first leak occurred since 2000, 42% reported the

[2] Advice on sampling protocol was provided by Dr. Robert Schulman and Ying Zhang of the Virginia Tech Statistical Consulting Center, April 2004.

first leak in the 1990's, 8% reported the first leak in the 1980's and 2% reported the first leak earlier than 1980 (Table 1). The relatively recent reporting of leaks could be due to the fact that respondents moved into their homes recently or it could be due to the fact that leaks have emerged as a problem only recently. However, analysis of the responses of residents who had been in their current residences since 1980 suggested that most leaks occurred recently for this group.

Table 1. The Year Pinhole Leaks Were First Reported

Year pinhole leaks were first reported	Total number of respondents with leaks	Percent
Since 2000	170	46
1995 to 1999	109	30
1990 to 1994	43	12
1980 to 1989	28	8
1970 to 1979	6	2
1960 to 1969	1	0
Before 1960	1	0
Do not Know	7	2
Missing observation	1	0
Total	366	100

Table 2 shows the distribution of pinhole leaks by year the residence was built. Older houses account for a higher proportion of pinhole leaks. For example, 45% of total respondents and 58% of respondents with pinhole leaks lived in residences built before 1960. Eight percent of all respondents and 1% of respondents with pinhole leaks lived in residences built since 1990. Further investigation is being done to determine possible interactions between the housing structure's age and location that might explain why older houses have more leaks.

More than half of respondents reporting pinhole leaks had leaks in horizontal pipes and a quarter of them had leaks in both vertical and horizontal pipes (Table 3). Only 8% had leaks in vertical pipes alone. Most leaks occurred along a straight length of pipe (Table 4). Most leaks were in the basement followed by the first floor (Table 5). Only 25% of respondents reported leaks occurring in the second floor or higher.

Pinhole leaks occurred in cold water pipes in half of the reported cases, in both cold and hot water pipes in 14% of the cases, and in hot water pipes only in 6% of cases (Table 6). Thirty-one percent of respondents were not aware of the type of water pipes where leaks occurred.

Table 2. The Age of the Household Property Relative to Pinhole Leaks				
Year house or apartment building was built	Total number of respondents	Percent[a]	Number of respondents with pinhole leaks	Percent
Since 2000	26	3	1	0
1990 to 1999	48	5	5	1
1980 to 1989	124	12	41	11
1970 to 1979	109	11	37	10
1960 to 1969	208	20	67	18
1950 to 1959	254	25	124	34
1940 to 1949	124	12	57	16
Before 1940	81	8	30	8
Do not know	39	4	2	1
Missing observations	9	1	2	1
Total	1,022	101	366	100

[a]Numbers do not sum to 100 due to rounding.

Table 3. Pinhole Leaks Occurred in Horizontal or Vertical Pipe		
Type of pipe	Number of observations	Percent
Horizontal pipe only	215	59
Vertical pipes only	30	8
Both	91	25
Do not know	29	8
Missing observation	1	0
Total	366	100

Table 4. Location of Leaks in Pipe		
Location	Number of observations	Percent[a]
Near a fitting	34	9
Along straight length	209	57
Both	91	25
Do not know	31	8
Missing observation	1	0
Total	366	99

[a]Numbers do not sum to 100 due to rounding.

Table 5. Location of Leaks in Dwelling		
Location	Number of observations	Percent[a]
Under slab or underground	11	3
Basement	268	73
First floor	147	40
Second floor	83	23
Third floor	5	1
Fourth floor or higher	4	1
Do not know	1	0
Missing observation	1	0

[a]Multiple choices per respondent were accepted. Percent = number reported divided by 366, the total number of respondents with leaks.

Table 6. Pinhole Leaks Occurring in Cold or Hot Water Pipes		
Type of pipe	Number of observations	Percent
Cold water pipes	179	49
Hot water pipes	21	6
Both	50	14
Do not know	115	31
Missing observation	1	0
Total	366	100

Pinhole Leak Reporting and Costs

Respondents reported pinhole leaks to several organizations. Plumbers or home supply stores received reports by 199 respondents (54% of respondents with leaks) (Table 7). Respondents listed water utility second most often (81 respondents), insurance company third (68 respondents) and neighbor or friend fourth (64 respondents). However, 84 respondents, almost one fourth of those with pinhole leaks, did not report the problem to anyone. Those not reporting the problem may have fixed the problem with or without advice from others on how to repair the leak.

Respondents provided information on the amount of time, financial costs, and stress resulting from pinhole leaks (Table 8). Thirty-nine percent of respondents with leaks spent less than 10 hours dealing with pinhole leaks; 21% spent between 11 and 20 hours; and 15% spent between 21 and 40 hours. Eighteen percent spent more than 40 hours dealing with the pinhole leak problem. Six respondents spent 100 hours or more dealing with leaks.

Table 7. Organization Contacted When a Pinhole Leak Occurs		
Name of organization	Number of respondents	Percent[a]
Plumber or home store supply	199	54
Water utility company	81	22
Insurance company	68	19
Neighbor/friend	64	17
Neighborhood association	18	5
Landlord	12	3
Health department	0	0
Other	23	6
Did not report leaks to anyone	84	23
Missing observations	6	2

[a]Multiple choices per respondent were accepted. Percent = number reporting to indicated organization divided by 366, the total number of respondents with leaks.

Table 8. Time Spent Dealing with Pinhole Leak Problems		
Number of hours	Number of respondents	Percent
Less than 10	144	39
11-20	76	21
21-40	56	15
41-80	40	11
More than 80	24	7
Do not know	22	6
Missing observations	4	1
Total	366	100

Forty percent of respondents reported that the expense of dealing with pinhole repairs and associated damage was less than $500; while 43% reported expenses between $500 and $5,000; and 11% reported more than $5,000 in expenses for pinhole leak repairs (Table 9). Six respondents reported expenses of $12,000 and one reported $25,000 in expenses. Many of the surveyed households pointed out that repairing pinhole leak damage requires repair/replacement of ceilings, walls, and other parts of the structure as well as repair to the plumbing. A few respondents moved out of their dwellings during the renovation periods, which added additional costs to their repair expenses. Others mentioned the priceless worth of personal belongings such as family photos, clothes, and furniture damaged from pipe failure.

Forty-four percent of respondents reporting leaks found the experience of pinhole leaks very stressful, and 30% found it somewhat stressful (Table 10). Twenty-seven percent of those reporting leaks experienced little or no stress. Many respondents indicated feeling aggravated, helpless, and in constant fear of a possible leak. Lack of knowledge on the possible causes of pinhole leaks adds to the overall anxiety felt by those with pinhole leaks. Furthermore, many people cite lack of third party involvement and responsibility as additional stress. The respondents feel left out in the case of water plumbing issues. Words of anger towards local water utilities, insurance companies and contractors are common.

Table 9. Costs of Repairing Pinhole Leaks and Associated Damage		
Amount of money	Number of observations	Percent
Less than $100	49	14
$100 to $500	94	26
$501 to $1,000	64	17
$1,001 to $3,000	55	15
$3,001 to $5,000	41	11
More than $5,000	42	11
Do not know	19	5
Missing observations	2	1
Total	366	100

Table 10. Stress from Dealing with Pinhole Leaks		
Stress level reported by respondents	Number of observations	Percent
Very stressful	160	44
Somewhat stressful	108	30
A little stressful	54	15
Not stressful	42	12
Missing observations	2	0
Total	366	101

Use of Water Treatment Devices or Purchased Drinking Water

The households with and without pinhole leaks use several types of appliances to treat their drinking water. Seventy-one percent of respondents with leaks and 76% of respondents without leaks use some type of water treatment device or purchase drinking water. Thirty-eight percent of all respondents reported that they purchase drinking water. The most common reasons given for using water treatment devices are to improve safety of drinking water and to improve taste or smell of drinking water. The survey did not ask how frequently respondents use water treatment devices or purchase drinking water.

Attitudes toward Water Safety and Quality

Respondents with and without pinhole leaks had similar views of home drinking water quality (Table 11). Over three fourths of respondents were somewhat or very satisfied with water quality. Only 4% of respondents with pinhole leaks and 3% without leaks were very dissatisfied with water quality. About 6% of all respondents had had the water in their current dwelling tested.

Respondents with and without pinhole leaks had similar views of home drinking water safety (Table 12). Seventy-five percent of respondents with leaks were somewhat or very satisfied with safety of their water compared to 79% of respondents without leaks. Nine percent of respondents with leaks and 11% of respondents without leaks did not know if their water was safe.

Table 11. Satisfaction with Home Drinking Water Quality by Respondents with and without Pinhole Leaks

	Respondents with pinhole leaks		Respondents without pinhole leaks	
Satisfaction Level	Number of observations	Percent	Number of observations	Percent
Very satisfied	125	34	161	34
Somewhat satisfied	156	43	215	45
Somewhat dissatisfied	66	18	82	17
Very dissatisfied	15	4	14	3
Missing observations	4	1	3	1
Total	366	100	475	100

Table 12. Satisfaction with Home Drinking Water Safety by Respondents with and without Pinhole Leaks

	Respondents with Leaks		Respondents without Leaks	
Satisfaction Level	Number of observations	Percent	Number of observations	Percent
Very satisfied	118	32	162	34
Somewhat satisfied	157	43	214	45
Somewhat dissatisfied	40	12	30	6
Very dissatisfied	14	4	11	2
Do not know	32	9	54	11
Missing observations	5	0	4	1
Total	366	100	475	100

Conclusions

Results from the survey indicate that pinhole leaks in copper home plumbing systems are a frequently reported problem in that region. Thirty-six percent of respondents had experienced at least one pinhole leak in their copper pipes. The rate of leaks among the population may be lower than reported in this sample if those who did not respond to the survey have fewer leaks. Most pinhole leaks occurred in the mid-1990's and the 2000's. Most respondents had 1 to 4 leaks; however, 17% reported 7 or more leaks. A higher frequency of leaks was reported in houses built prior to 1960. Pinhole leaks can have high financial, emotional and time costs. Most leaks occurred in cold water, horizontal pipes along a straight length of the pipe located either in the basement or on the first floor.

Over half of respondents with leaks reported expenditures of at least $500 for repairing leaks and associated damage. Seven respondents cited $12,000 in repair expenses and one person reported more than $25,000 in damage from pinhole leaks. Almost a third of those reporting leaks spent at least 20 hours dealing with pinhole leaks and related damage and almost three fourths found the experience somewhat or very stressful. Although respondents are aware of the pinhole leak problem, their perceptions of water quality, safety, taste and smell are similar. Most respondents use some type of water treatment device or purchase drinking water. Respondents mentioned improving water safety and water taste and smell as reasons for using such devices or purchasing bottled water.

Respondents with leaks contacted various organizations or individuals with plumber/home supply store, water utility company, insurance company, and neighbors being mentioned most often. However, involvement of water utility and insurance companies was not adequate enough in solving this problem according to their customers.

The study presented here is only a preliminary research, which helped the investigating team to gather information on the extent of the pinhole leak problem. The next step of the pinhole leak study is to examine households' preferences for plumbing materials and their willingness to pay for improved water distribution services. A national telephone survey of households and commercial establishments is being developed to determine the incidence of pinhole leaks, estimates of pinhole leak damages, and willingness to pay to avoid pinhole leak problems. Findings from the survey will assist water utilities, EPA, and other public agencies as well as home and business owners in determining necessary steps to improve water quality and safety as well as water distribution services.

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EMERGING TRENDS IN CLEAN WATER ACT LITIGATION: DRIFTING AWAY FROM SCIENTIFIC PRINCIPLES?

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ABSTRACT

Water science is seldom well represented in litigation. Indeed, an analysis of emerging Clean Water Act litigation reveals that scientific principles are being lost in common-law doctrinal development. At issue in this litigation is whether a permit is required for the transfer of unaltered water containing pollutants to another body of water. Courts have responded with some bright-line tests, but those approaches strain scientific principles in complex hydrologic settings such as wetlands. The recent Supreme Court case *South Florida Water Management District v. Miccosukee Tribe of Indians* demonstrates this point; the Court struggled with applying tests for distinct surface-water bodies to the Everglades, where ground water and surface water are so closely connected. A better approach would be to re-examine traditional causation doctrines: the "substantial factor" test may best meld science and law for these types of cases. More broadly, this analysis highlights the continuing importance of dialog between water law and water science to ensure scientifically supportable outcomes.

INTRODUCTION

Water law in the courts has always suffered from a muddying of scientific principles.[i] Indeed, few would argue that two-party, adversarial proceedings are the ideal fora for resolving complicated water-quality and water-use issues.[ii] An emerging generation of Clean Water Act ("CWA")[iii] litigation illustrates some of the resultant difficulties, but also hints at employing better approaches rooted in traditional common-law doctrines.

At issue in this developing litigation is the necessity for a National Pollution Discharge Elimination System ("NPDES")[iv] permit—called the "cornerstone" of the CWA[v]—when unaltered water containing pollutants is discharged to another body of water via a point source. The question is deceptively simple-looking, but a closer look at what it means to "add" water from one body of water to another reveals a need for hydrological realities to better inform judicial doctrine-making.

Courts confronting the above issue have concluded that dam discharges are not additions, while interbasin transfers are. Confined to the facts of those cases, the tests employed are relatively straightforward and are not particularly troubling hydrologically; however, the assumptions underlying those tests cannot apply in every hydrological setting. In fact, when the Supreme Court took up the issue in the recent case *South Florida Water Management District v. Miccosukee Tribe of Indians*.[vi] Specifically, the Court struggled with how to make the law conform to the hydrological realities of the Everglades.

This paper begins by describing the void in the CWA definition which bears on the necessity of an NPDES permit for unaltered water transfers. A spectrum of court cases is presented, culminating with an analysis of *Miccosukee*. Finally, an exploration of better approaches reveals that a doctrine rooted in traditional tort law, the "substantial factor" test, better suits both water science and water law. This doctrine accounts for the variation and uncertainty in natural systems while providing a familiar method of analysis for the courts. Furthermore, the analysis reveals that the gaps between water law and water science need not be so difficult to bridge.

BACKGROUND

The NPDES permitting scheme is perhaps one of the most prominent features of the CWA. Under that scheme, "the discharge of any pollutant by any person [is] unlawful" without an NPDES permit.[vii] "Discharge" is defined as "any addition of any pollutant to navigable waters from any point source."[viii] Although "pollutant," "navigable waters," and "point source" are defined,[ix] Congress failed to define the term "addition." The meaning of that word is the focal point of the litigation considered here.

A case involving a dam, *National Wildlife Federation v. Gorsuch*,[x] touched off the debate whether unaltered water could ever count as an addition. There, the District of Columbia Circuit Court of Appeals held that downstream discharges from dams are not subject to NPDES requirements, even if dam-induced water quality changes make the impounded water of poorer quality than the downstream water. In the absence of Congressional direction in the CWA, this conclusion was largely premised on the court's determination that it owed deference to the EPA's interpretation of the words "pollutant" and "addition."[xi] Of most relevance here, the court accepted the EPA's argument that "addition" meant that a pollutant must be introduced to navigable water *from the outside world*.[xii] Thus, water merely passing through a dam could not be said to constitute an "addition."[xiii]

Those courts considering *Gorsuch*'s application to interbasin transfers have had little difficulty drawing distinctions. Where a ski resort pumped water from a polluted river into a pristine pond for snowmaking, for example, the First Circuit Court of Appeals ruled that it constituted an "addition" and required an NPDES permit. That case, *Dubois v. U.S. Department of Agriculture*,[xiv] distinguished *Gorsuch* as having involved movement of water within a single water body.[xv] The court considered but rejected the defendant Forest Service's contention that because the river and pond were "hydrologically connected"—water flowed naturally from the pond to the river—there was no introduction of pollutants from the outside world.[xvi] That approach could not apply, reasoned the court, because water from the river would never flow uphill to the pond.[xvii] Indeed, because any transfer of water from the river to the pond *would not occur naturally*, it constituted an addition to the pond.[xviii]

The Second Circuit echoed this rationale in *Catskill Mountains Chapter of Trout Unlimited, Inc. v. City of New York*.[xix] In that case, the plaintiffs argued that New York City's diversion of water from one sub-basin of the Hudson River to another violated the CWA.[xx] The court held that an NPDES permit was required. It acknowledged the EPA's position that to be an "addition," a pollutant must be introduced "into navigable water from the outside world."[xxi] The court further explained that "outside world" would be "any place outside the particular water body to which pollutants are introduced."[xxii] Distinguishing *Gorsuch*, the court wrote: "If one takes a ladle of soup from a pot, lifts it above the pot, and pours it back into the pot, one has not 'added' soup or anything else to the pot.[xxiii] Because the *Catskill Mountains* transfer was more akin to moving water from one pot to another, the court held that an addition had occurred and an NPDES permit was required.[xxiv]

From a hydrological standpoint, *Catskill Mountains*, *Dubois*, and *Gorsuch* seemed to offer workable tests; where drainage basins or surface water flow was easily mapped, one need only consider whether a transfer of water was different from natural flow conditions. The weaknesses of this approach became apparent, however, in *South Florida Water Management District v. Miccosukee Tribe of Indians*.[xxv] There, the Supreme Court grappled with a similar CWA challenge in a very different hydrological setting: the Florida Everglades.

Discussion of the case requires an understanding of both the historical functioning of the Everglades and the modern-day scenario. As the Supreme Court described in *Miccosukee*, the Everglades has been "fundamentally altered" hydrologically.[xxvi] Once exhibiting southward sheet flow of surface water and ground water, much of the Everglades is now covered with "a comprehensive network of levees, water storage areas, pumps, and canal improvements" constructed by the U.S. Army Corps of Engineers.[xxvii] The ongoing scenario in *Miccosukee* is a project consisting of the following: a canal ("C-11") that collects ground water and rainwater from an area used for urban, agricultural, and residential purposes; a pump station ("S-9") that pumps water from the canal when its level exceeds sea level; an undeveloped water conservation area ("WCA-3") into which the pump discharges water; and two levees ("L-33" and "L-37") designed to prevent the water in the water conservation area from flowing east and returning to the area drained by the canal.[xxviii] Due to the land use in the area drained by C-11, that water contains elevated levels of phosphorous, differing from the water in WCA-3.[xxix]

The plaintiffs, the Miccosukee Tribe of Indians of Florida, contended that the discharge of C-11 water into WCA-3 violated the CWA because it was done without an NPDES permit.[xxx] Relying on *Dubois*, the district court agreed and stated that the determinative test for "addition" was whether the transfer of water would occur naturally.[xxxi] While affirming that holding, the Eleventh Circuit Court of Appeals employed a slightly different analysis rooted in causation principles:

> [F]or an addition of pollutants to be from a point source,
> the relevant inquiry is whether—*but for the point source*—

> the pollutants would have been added to the receiving body of water. We, therefore, conclude that an addition from a point source occurs if a point source is the *cause-in-fact* of the release of pollutants into navigable waters.[xxxii]

Furthermore,

> When a point source changes the natural flow of a body of water which contains pollutants and causes that water to flow into another distinct body of navigable water into which it would not have otherwise flowed, that point source is the *cause-in-fact* of the discharge of pollutants.[xxxiii]

The Eleventh Circuit's analysis therefore redirected the inquiry from the "occurring naturally" rubric to one of strict, "but-for" causation; that is, its test asked whether pollutants would be released in the absence of the point-source discharge.

The Supreme Court seemed to struggle with what test would be appropriate; it vacated the court of appeals' judgment and remanded the case, concluding that there were factual issues whether the two bodies of water were indeed distinct.[xxxiv] The Court noted that there was evidence in the record that water travels between the two areas as "seepage and groundwater flow," and it accepted the defendant's argument that it was possible the areas were "two hydrologically indistinguishable parts of a single water body."[xxxv] Further, the Court concluded that there were issues as to how the relationship between the areas should be assessed: the plaintiffs argued for a focus on the ecosystem characteristics of the two areas, while the defendant would have focused on the hydrological connectivity between the areas.[xxxvi] According to the Supreme Court, however, the district court had applied a third test—one that no party endorsed—in reasoning that the areas were distinct because the transfer of water from the canal area to the water conservation area would not occur naturally.[xxxvii]

On remand, therefore, the district court will be required to reconsider the evidence and choose a test for assessing the relationship between C-11 and WCA-3. As described below, the district court would do well to explore alternatives to those posited by the Court in hopes of better aligning legal doctrine with hydrology.

ANALYSIS

The above discussion showcases one of the broader tensions between science and law. Courts must make decisions on the facts presented in each particular case, but a particular factual scenario does not often capture a full scientific background. Further, the courts are usually dependent on the parties to provide the necessary scientific expertise bearing on the issues. Inevitably, a new factual scenario will come along that strains previously developed doctrine, at which point it will become critical to evaluate the doctrine in light of scientific principles.

The "addition" cases illustrate these difficulties. Congress did not consider the term "addition" at all, and the EPA—which is arguably better-equipped than the courts to consider scientific issues more broadly—has not formally defined it either. Beginning with *Gorsuch*, the courts have attempted to formulate a workable test, but *Miccosukee*'s unique hydrology has made that task more difficult. Although the Supreme Court seemed to suggest that the district court should pick a single test (*i.e.*, ecology, hydrology, or outside world), none of those tests capture scientific reality. Wetlands, after all, are classified by their ecological *and* hydrological characteristics.[xxxviii] Further, the "outside world" test, which was serviceable in surface-water cases like *Catskill Mountains*, seems awkward in a setting where surface water and ground water are so closely related.[xxxix]

For these same reasons, the Eleventh Circuit's but-for causation analysis is also inappropriate. Under traditional tort law, but-for causation requires that a single cause bring about a harm; as the Restatement (Third) of Torts describes,

> Tortious conduct must be a factual cause of physical harm for liability to be imposed. Conduct is a factual cause of harm when the harm would not have occurred absent the conduct.[xl]

Yet that standard does not capture the facts the *Miccosukee* Court seemed to struggle with: multiple causes of a single harm. The Court catalogued several ways in which the WCA and C-11 waters might intermingle, focusing on seepage and ground-water flow from WCA-3 beneath the levees. It also noted that if S-9 were shut down, the C-11 drainage area would flood, "call[ing] into question the Eleventh Circuit's conclusion that S-9 is the cause in fact of phosphorous addition to WCA-3."[xli] All of these comments suggest that the Court believed there was evidence in the record to show that phosphorous might enter WCA-3 *even in the absence of pumping*.

It was undisputed, however, that S-9 *did* add phosphorous to WCA-3. Whether phosphorous does or could enter in another manner should be irrelevant to the NPDES question: taken to its extreme, that approach would mean that a downstream polluter would not have to treat waste if it contained a pollutant discharged by an upstream polluter. This result runs counter to the entire scheme of the CWA,[xlii] which shifted the focus of previous water-quality statutes from receiving waters to pollutants themselves.

An approach that would more closely mirror scientific reality is embodied in an exception to the but-for test:

> If multiple acts exist, each of which alone would have been a factual cause . . . of the physical harm at the same time, each act is regarded as a factual cause of the harm.[xliii]

This "substantial factor" test is almost universally accepted as the appropriate test when two (or more) causes combine to cause a result and either one alone would have brought about the same result.[xliv]

The case of phosphorous entering the Everglades presents a similar situation. Phosphorous might come from any number of sources, but in *Miccosukee*, C-11 certainly puts excess phosphorous into WCA-3. There is little doubt that it is a substantial factor in polluting WCA-3, even if there might be other sources of phosphorous that also contaminate WCA-3. To be sure, this approach focuses on a pollutant rather than a particular body of water, in contrast to the "outside world" test. But as noted already, a constituent-based approach is consistent with the CWA scheme.

Furthermore, the substantial-factor test eliminates "baseline" problems. For example, the Supreme Court alluded to what would happen if S-9 were shut down and seemed to suggest that the resultant intermingling of waters might negate any present-day "addition" via C-11.[xlv] That view presumes a baseline of post-project conditions, in which man-made structures are removed. It is extremely unlikely that that would happen in the foreseeable future, and so it hardly makes sense to construct a legal test upon such a baseline.[xlvi] Nor would a natural-conditions baseline aid the analysis, because it would presume the once-upon-a-time sheet flow of pristine, nutrient-poor ground water and surface water; it would be an absurd result to say that because Everglades water was once a single pot of soup, a now-smaller pot should not be protected.

The substantial factor test should often yield the same results as the "occurring naturally" and "outside world" tests. Its causation-based pedigree, however, leaves room for those hydrological scenarios that are not so straightforward. As a result, courts may be able to achieve outcomes in CWA litigation that better reflect hydrological reality.

CONCLUSION

Emerging CWA litigation reveals that scientific principles may be losing ground in doctrinal development. By considering basic hydrologic principles and broader legal doctrine, however, it appears that both doctrinal and scientific needs can be met. There are several lessons to be learned from this analysis. First, the substantial factor test has much to offer the legal system as a way to understand and evaluate hydrological issues in NPDES litigation. It captures a variety of hydrological settings and offers a rubric familiar to courts and lawyers. Second, there may be other familiar doctrines in traditional legal analysis that can help obtain outcomes that properly reflect scientific reality. Finally, there is a continuous need for improved dialog between science and the law: only through an understanding of science can the legal system develop workable doctrines that generate realistic results upon which decision-makers can rely in the future.

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[i] *See, e.g.,* State v. Michels Pipeline Constr., Inc., 217 N.W.2d 339, 344 (Wis. 1974) (describing historical reluctance to regulate ground water because it is too "mysterious").

[ii] *See, e.g.*, Georgia v. U.S. Army Corps of Eng'rs, 223 F.R.D. 691 (N.D. Ga. 2004) (describing detailed history of water disputes between Alabama, Georgia, and Florida, and exercising *Colorado River* abstention).
[iii] 33 U.S.C. §§ 1251-1387 (2001 & Supp. 2005).
[iv] *Id.* § 1342.
[v] Natural Resources Defense Council v. U.S.E.P.A., 822 F.2d 104, 108 (D.C. Cir. 1987).
[vi] 541 U.S. 95 (2004).
[vii] 33 U.S.C. § 1311(a).
[viii] 33 U.S.C. § 1362(12).
[ix] *See* 33 U.S.C. §§ 1362(19), (7), & (14). Of course, a definition in a statute does not preclude litigation. *See* S. Fla. Water Mgmt. Dist. v. Miccosukee Tribe of Indians of Fla., 541 U.S. 95, 104-05 (2004) (interpreting "point source"); Nat'l Wildlife Fed'n v. Gorsuch, 693 F.2d 156, 171-74 (D.C. Cir. 1982) (interpreting "pollutant"). *See generally* Solid Waste Agency of N. Cook County v. U.S. Army Corps of Eng'rs, 531 U.S. 159 (2001) (interpreting "navigable waters").
[x] 693 F.2d 156.
[xi] *Id.* at 166-70; *id.* at 168 (the "EPA has never changed its basic position that dams generally do not require NPDES permits"). *But see* Catskill Mountains Chapter of Trout Unlimited, Inc. v. City of New York, 273 F.3d 481, 489-91 (2d Cir. 2001) (concluding subsequent Supreme Court authority required that such deference was not proper because the EPA's position was never adopted in a rulemaking or other formal proceeding); Alison M. Dornsife, Comment, *From a Nonpollutant into a Pollutant: Revising EPA's Interpretation of the Phrase "Discharge of Any Pollutant" in the Context of NPDES Permits*, 35 Envtl. L. 175 (2005) (arguing for lesser standard of deference to EPA's position that discharges of dam-created pollutants do not require NPDES permit).
[xii] *Id.* at 165.
[xiii] *See also* Nat'l Wildlife Fed'n v. Consumers Power Co., 862 F.2d 580 (6th Cir. 1988) (relying heavily on *Gorsuch* and concluding water in a pumped-storage facility did not constitute an addition when recirculated from its source).
[xiv] 102 F.3d 1273 (1st Cir. 1996).
[xv] The court also rejected as having "no basis" the district court's conclusion that the river and pond were all part of a "singular entity, 'the waters of the United States' " such that the bodies of water were not to be considered individually in the NPDES context. *Id.* at 1296.
[xvi] *Id.* at 1297-98.
[xvii] *Id.* at 1298.
[xviii] *Id.* at 1297.
[xix] 273 F.3d 481 (2d Cir. 2001).
[xx] *Id.* at 484. The source water had elevated temperatures, turbidity levels, and suspended solids.
[xxi] *Id.* at 491 (quoting *Gorsuch*, 693 F.2d at 165). The court concluded, however, that subsequent Supreme Court authority undermined *Gorsuch* to the extent that court had given broad deference to the EPA. *See supra* note xi.
[xxii] *Id.*
[xxiii] *Id.* at 492.

[xxiv] *Id.*
[xxv] 541 U.S. 95 (2004).
[xxvi] *Id.* at 100.
[xxvii] *Id.*
[xxviii] *Id.*. For an analysis of water-quality trends in the Everglades, see generally Ronald A. Miller et al., *Water Quality in Big Cypress National Preserve and Everglades National Park—Trends and Spatial Characteristics of Selected Constituents*, U.S. Geological Survey Water Resources Investigation Report 03-4249 (2003).
[xxix] *Id.* at 101.
[xxx] *Id.* at 102.
[xxxi] Miccosukee Tribe of Indians of Fla. v. S. Fla. Water Mgmt. Dist., Nos. 98-6056 & 98-6057, 1999 WL 33494862, at *6 (S.D. Fla. Sept. 30, 1999) (citing Dubois v. U.S. Dep't of Agric., 102 F.3d 1273, 1297 (1st Cir. 1996)).
[xxxii] Miccosukee Tribe of Indians of Fla. v. S. Fla. Water Mgmt. Dist., 280 F.3d 1364, 1368 (11th Cir. 2002) (footnote omitted) (emphasis added).
[xxxiii] *Id.* (emphasis added).
[xxxiv] 541 U.S. at 112. In a three-part opinion, the Court first clarified that a "point source" "need not be the original source of a pollutant." *Id.* at 105. This first portion was the only actual holding of the case. In the second part, the Court discussed but did not rule upon the Solicitor General's "unitary waters" theory, which was much like the "singular entity" theory raised and rejected in *Dubois*. *Id.* at 105-09; *see supra* note xv (describing theory). This theory was thoroughly debunked in Matthew Duchesne, Comment, *Discharging the Clean Water Act's NPDES Requirements: Why the "Unitary Waters" Theory Does Not Hold Water*, 23 Va. Envtl. L.J. 461 (2005) (contending theory has no basis under proper statutory construction).
[xxxv] 541 U.S. at 109-10. This argument seemed reminiscent of the Forest Service's "hydrologic connectivity" test rejected in *Dubois*. *See supra* notes xvi-xvii and accompanying text.
[xxxvi] 541 U.S. at 110-11.
[xxxvii] *Id.*
[xxxviii] The generally accepted definition of "wetlands" developed by Cowardin et al. provides that

> WETLANDS are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of the year.

Lewis M. Cowardin et al., *Classification of Wetlands and Deepwater Habitats of the United States*, Performed for U.S. Department of the Interior, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC, FWS/OBS-79/31 (Dec. 1979).

[xxxix] *See Miccosukee*, 541 U.S. at 110 ("water flows easily between ground and surface waters, so much so that 'ground and surface waters are essentially the same thing' " (citation omitted)); *see also* Judson W. Harvey et al., *Interactions Between Surface Water and Ground Water and Effects on Mercury Transport in the North-Central Everglades*, U.S. Geological Survey Water Resources Investigation Report 02-4050, at 76 (2002) (describing increased recharge and discharge in Everglades Nutrient Removal Project and WCA-2A since pre-drainage conditions as result of water-management activities, but describing reduced magnitude in interior WCA-3).
[xl] Restatement (Third) of Torts: Liability for Physical Harm § 26 (Proposed Final Draft No. 1, 2005).
[xli] 541 U.S. at 111.
[xlii] George A. Gould & Douglas L. Grant, Water Law 532 (5th ed. 1995) ("The principal focus of the amendments is on the pollutants, not on the harm done or the water itself.").
[xliii] *Supra* note xl, § 27.
[xliv] *Id.* Reporter's Note cmt. a.
[xlv] 541 U.S. at 111 (If S-9 were shut down, the resultant "flooding might mean that C-11 would no longer be a distinct body of navigable water, but part of a larger water body extending over WCA-3 and the C-11 basin. It also might call into question the Eleventh Circuit's conclusion that S-9 is the cause in fact of phosphorous addition to WCA-3." (internal quotations and citations omitted)).
[xlvi] In fact, the Eleventh Circuit overturned the district court's preliminary injunction, which would have required the defendants to cease operating S-9 without an NPDES permit. As the district judge himself commented, "I was not aware that the injunction would have the dire consequences of literally opening the flood gates." Miccosukee Tribe of Indians of Fla. v. S. Fla. Water Mgmt. Dist., 280 F.3d 1364, 1371 (11th Cir. 2002).

MEASURING SUCCESS IN COLLABORATIVE WATERSHED-BASED MANAGEMENT: URBAN RIVER PLANNING ON THE ANACOSTIA RIVER

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KEY WORDS: watershed management, conflict resolution, Anacostia River

ABSTRACT

There are collaborative watershed partnerships in every state and many estimate that this new form of natural resource management is continuing to grow. However, there are critiques of collaborative watershed planning and management and uncertainty about how to measure the success of collaborative watershed efforts.

The Anacostia River has been selected as an Urban River Pilot Program by the U.S. EPA and the U.S. Army Corps of Engineers. The U.S. EPA is working with a diverse group of stakeholders to develop a comprehensive action plan to restore the river and to integrate river planning with local land uses. The authors of this paper are working with this collaborative and have experience with other collaborative watershed efforts. The presentation uses the Anacostia project to illustrate research findings and challenges to collaborative watershed management.

The presentation reviewed recent research on watershed partnerships and other collaborative water resource management innovations and discussed the reasons for the growth of collaborative watershed planning and management. It detailed empirical research that has examined the environmental and social outcomes from collaborative watershed management projects. The paper connected the findings from this research to conflict resolution theories and experience. Conflict resolution theory helps explain why some partnerships are more effective than others. Finally, the presentation discussed how the research and theory guides the development and management of partnerships that are collaborative, fair, and have impact.

INTEGRATING KNOWLEDGE FROM "HERE" WITH KNOWLEDGE FROM "AWAY": THE FAIRFAX COUNTY NEIGHBORHOOD STORMWATER COLLABORATIVE PROCESS

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KEY WORDS: conflict resolution, public policy, stormwater

ABSTRACT

Conflicts over water are similar to many conflicts in communities over land use, resource allocation, and planning. However, conflicts over water are likely to be more intense with more possibilities for rapid escalation. The likelihood for intensity and escalation is connected to the deeply symbolic, spiritual, and cultural meanings of water. Conflicts over water involve stakeholders from different social systems and institutions: from environmental to social, organizational, technical, cultural, and religious.

Public policies and decisions over how a community should provide safe drinking water and manage storm water are likely to cause real controversy and conflict. These conflicts are exacerbated because local knowledge about water is disregarded in planning, policymaking, and problem solving. Scientific and technical knowledge is often privileged. The presentation discussed a case study of a collaborative community process that involved neighbors, local elected officials, county water engineers and others in solving a local storm water problem. The community collaborative developed comprehensive approaches to integrating local knowledge with scientific knowledge and organizing both to support decision-making.

The presentation discussed findings from a Ford Foundation sponsored applied research project. The presenters detailed basic principles for managing and integrating local knowledge with scientific and technical knowledge, strategies for organizing and integrating knowledge, and the different kinds of outcomes that result from the integration of different epistemological standpoints. The principles, strategies, and outcomes was illustrated with case information from the Fairfax County storm water collaborative.