Virginia Stormwater Management Program (VSMP)
Regulatory Advisory Panel Subcommittee Meetings
September 1, 2010
Patrick Henry Building, Richmond, Virginia

The minutes include an overview of the discussions and actions that occurred within the four Stormwater Regulatory Panel Subcommittees that met on this date (Water Quantity, Offset, Grandfathering and Water Quality subcommittees).

Water Quantity Subcommittee

Attendees
Mike Rolband-Chair
Steve Herzog
Daniel Proctor
Ingrid Stenbjorn
Jenny Tribo
Joe Battiata
Rick Parrish (left at 1:30 PM)
John Olenik
Jerry McGranner
Aislinn Creel
Greg Johnson
Keith White
Judy Cronauer
Todd Chalmers
DCR Staff present: Lee Hill and Mike Foreman

Chair Rolband welcomed "Quantity" subcommittee members to the meeting, thanked them for their continued interest and participation plus reminded members of the "Sunshine Law" and group discussion

Definitions Review
Part I definitions were discussed including the following:

- Bank full channel and flood prone area: Flood prone area needs local flexibility element added.
- Main Channel: Add definition to read "the portion of the conveyance system that contains base flow and smaller, more frequent storm events".
- Adequate channel: Modify to read "will convey the designated storm event within the storm conveyance system".
- Channel: Remove definition.
- Comprehensive Stormwater management plan: Keep as is.

- Development: Keep as is.
- Flood fringe/Floodway/Floodplain: Modify as proposed in "side by side" meeting notes.
- Impervious Cover: Modify to remove listed examples at end of definition.
- Man-made Stormwater Conveyance System: Add the phrase, "except for restored stormwater conveyance systems," and move under Stormwater Conveyance System definition.
- Natural Channel design concepts: Keep as is.
- Natural Stormwater Conveyance System*: Change "bankfull" to "main" channel and move under Stormwater Conveyance System definition.
- Natural stream: Keep as is.
- Outfall: Keep as is.
- Peak flow rate: Keep as is.
- Planning area: Keep as is.
- *Point of Discharge: Keep as is for now.
- Restored Stormwater Conveyance System: Change "bankfull" to "main" channel and move under Stormwater Conveyance System definition.
- Runoff characteristics: Include only peak flow rate, volume, and flow duration in definition
- Stable: Remove definition.
- Stormwater Conveyance System: Modify to serve as overarching definition.
- Unstable: Remove definition.
- **Localized Flooding: Add a definition that refers to the smaller-scale flooding that may occur outside of a stormwater conveyance system. This may include high water, ponding, or standing water from stormwater runoff which is likely to cause damage or unsafe conditions.
- Sheet Flow: Following Judy's review, she determined with the subcommittee concurring, to leave as is.

***Lee will review point of analysis/discharge for clarity**
****Ingrid to further analyze this localized flooding definition for clarity.***

<u>Review of Proposed Regulations-What are the issues?</u>

Beginning with 4VAC 50-60-66, Chair Mike Rolband led the subcommittee through the proposed regulations and identified issues of concern. Following the issue identification process, the subcommittee agreed to address the identified issues specifically and in detail. Sections with identified issues of concern were as follows:

B. Channel Protection
C. Flood Protection
E. Sheet Flow
G. Pre-Development Runoff Characteristics
H. Point of Discharge/Channel Analysis

Between subcommittee meetings, work efforts led to the following decisions regarding this section of the regulations. Subcommittee members believe these changes would greatly simplify the regulations. These recommended changes were agreed to by the subcommittee.

Remove "stable" and unstable" from the regulations totally.
Remove "Subsection H"
Consider a % reduction for pre-development with it being forest or pasture
Pre-development "floor" is forest condition
For Formula in B.a.ii (new nomenclature): place 0.8 after $\leq$ sign
Forest condition caveat---$Q_{developed}$ no less than $Q_{forested}$
No increase in peak Q dev or Q dev be required to be $\leq [Q_{forested} \times RV_{forested}] / RV_{developed}$

Steve and Joe to work on language on B.a.i.

Flood Protection
***Lee will work on language with all group members reviewing regulatory language on this section**

4VAC 50-60-72

B. Use of the word "ultimate": language addition…"analysis shall be based on watershed characteristics and how the ultimate development condition of the subject project shall be addressed".
C. Suggestion not to specify analytical method: Determined to be OK as is.
D. Suggestion that "200" acre drainage area is too high: Determined to be OK as is.

4VAC 50-60-85

A. Subsection regarding the use of in-stream/Wetland Stormwater Ponds: Recommended to be removal from regulations.
B. Subsection regarding stormwater BMPs in FEMA designated floodplains: Recommended to be removal from regulations.
C. 100-Year Design Standard: Determined to be OK as is.

Subcommittee members believed they had accomplished most of the work given to them but stated that coordination with the other 3 groups, particularly the "quality" group, would be important to ensure a clear set of draft regulations. In addition, the group thought if they could see the changes in one place together that would be helpful and help ensure clarity for their sections. Chair Rolband requested DCR staff to consider this coordination request.

The next full Regulatory Advisory Panel meeting is scheduled for September 15. This may be the proper time to coordinate the 4 groups input.

Side by Side

A separate update of the "side by side" comparison will be prepared by Mike Rolband.

Offset Subcommittee

Attendees
Doug Beisch – Chairman
Barbara Brumbaugh
Shannon Varner
Ann Jennings
Mike Flagg
Jeff Perry
Alyson Sappington
Kurt Stephenson
Katie Frazier
DCR Staff present: Christine Watlington

Chairman's Welcome and Discussion

The Chairman welcomed everyone to the meeting and completed an overview of the previous meeting on August 16, 2010. He also explained some of the background materials that were sent our prior to this meeting. A Chesapeake Stormwater Network paper prepared by Tom Schuler was provided and is primarily focused on Maryland and its ultra urban areas.

One subcommittee member asked about guidance from the Environmental Protection Agency (EPA) regarding offsets. It was stated that there was draft guidance in development that seemed to be very broad in allowing states to develop their own program and does not seem to be too prescriptive. It was recognized that there were difference between the Maryland and Virginia stormwater programs.

The subcommittee then discussed a proposal regarding the state buy-down program. In this program, the developer could conceivably make a payment; the money would then go into an account and then use the money to contract with offset/off-site credit providers. This would set up a competitive bid process and will let credit suppliers know the demand for credits in each river basin. Any creditor would be able to make bid proposals (proposals could include land conversion, stream restoration, urban restorations, biomass harvesting, and innovative technology). This proposal would require up front capitalization and the development monies would ensure the continuing ability to provide for a next round of bid proposals. This would be a reverse auction type of bid process, where the idea is to award the funds to the lowest cost project. This proposal has potential to be utilized for more than stormwater credit reductions. There would be risk involved with this type of proposal; however, there would be a number of ways of reducing the risk including, having permanent credits in place, including the cost of the risk into the cost of the credit, and maintaining a baseline for the credits.

The idea of baseline requirements before an individual would be able to market nutrient reduction credits was mentioned as a concern by several members of the subcommittee. One member stated that the baselines and targets are variable depending on the sensitivity analysis that had been completed. It was decided that the subcommittee was intrigued by the proposal and did not want to preclude this from being an option.

It was noted by a member that the offsite options were very complex and could be very confusing for individuals with nutrient reduction credits available. It was mentioned that farmers were very familiar with the rules regarding the wetland mitigation program and it might be beneficial to structure the offsite options similarly to that program. It was also mentioned that there were to be administrative costs for all the options and that should be taken into consideration.

There was consensus that some sort of state buy-down option should be provided, but that the program that was currently in the regulations could use significant improvement. There were additional questions concerning the wastewater treatment plant options for offsite compliance. It was mentioned that there was a reverse payment program with the price per pound of reduction in the regulation. The price per pound of reduction was adjusted once every 5 years; however, it was noted that this program had not been used to date. The committee agreed that probably all five options need to be kept in the regulations but additional clarification and guidance was needed.

The subcommittee discussed the issue of perpetuity. There was a discussion of whether the issue of perpetuity related only to offsets. There was also a discussion of whether a maintenance agreement and a funding source to ensure the proper operation and maintenance of a best management practice would be deemed perpetual. There was the acknowledgement that local governments do try very hard to make things better for their communities and actually do want to do the right thing for their community.

A question was asked regarding the "hierarchy" of options within the offsite compliance options. As the law exists today, it was explained that local government programs have the priority as long as those programs are achieving equivalent nutrient reductions as offsets. There was a discussion of whether the best management practices utilized for the offsite options would need to be "on the ground" prior to the commencement of construction. There was acknowledgment that there needs to be a more open market for offsets and potentially an easier process to allow the use of offsets. It was decided that the list of tradable practices should not be limited but could include agricultural practices and land conversion, urban retrofits, stream restoration and pond retrofits, biomass harvesting, bioretention, algae removal, and other innovative practices.

There was a decision by the group to table the issue of whether nitrogen and sediment were also tradable. It was mentioned by one member that most sediment loads are controlled by erosion and sediment control practices during construction and quantity controls for post construction.

There was a discussion concerning the use of offsets and the level at which a developer would be able to utilize offsets. There were two concepts discussed. One regarded the use of a percentage reduction on site (if a developer achieved a 65% efficiency of best management practices, which would be similar to achieving the limit of technology), then the developer would be allowed to achieve the remainder through off-site compliance. The other concept would be percentage of the total nutrient reduction achieved on site (an example would be that if a developer achieved 75% site on site then the rest would be able to be achieved off-site).

Grandfathering Subcommittee

Attendees
Mike Toalson, Chairman
Assad Ayoubi
Peggy Sanner
Bethany Bezak
Philip Abraham
Bob Kerr
John Paul Woodley
DCR Staff Present: Ryan Brown and Michael Fletcher

Mr. Toalson noted that the meeting of the full Regulatory Advisory Panel was scheduled for Wednesday, September 15, 2010.

Mr. Toalson said that the subcommittee had been close to arriving on language at the previous meeting. He noted that some would like for everything vested to be grandfathered, others suggested that grandfathering be allowed only if an application had been submitted.

Mr. Toalson said that he would like to see the process simple, but fair. He said he would like to see the subcommittee get as close to possible to consensus. He said that once the language goes to the RAP and is included in the draft regulations there would be ample time for public comment.

Mr. Toalson, Ms. Sanner and Mr. Abraham submitted draft versions of the language. Copies of those versions are available from DCR.

Ms. Sanner said that in her version there would be a set of plans and plats subject to grandfathering provided they gave reasonable assurance that the activity would conform to the existing regulations. She said that because of the concern with the term “reasonable assurance” she suggested adequate demonstration, which would be included in the definitions. She said that the intent was to propose to grandfather plans that have coverage under the general permit or meet the requirements of the next section, providing that they were approved by the locality and also that the plan was submitted to the permit issuing authority.

Ms. Sanner said the intent was that the plan be submitted, but not that it had to be approved by the permit issuing authority.

Mr. Kerr said that he was concerned about a mandate to submit a plan for preliminary approval.

Mr. Brown said that it would be awkward for DCR as the permit issuing authority to receive those plans where no permit had been applied for. He suggested that the plan be required at the time of submission for the permit.

Mr. Toalson's suggested language was reviewed. He said that the language was the same as previously discussed with the exception that those with a current permit be grandfathered until June 30, 2019.

After the discussion, the subcommittee reached general consensus on the following language:

Sample Grandfathering Language
September 1, 2010 Grandfathering Subcommittee Meeting

4VAC50-60-48. GRANDFATHERING

Until June 30, 2019, any land disturbing activity for which a currently valid proffered or conditional zoning plan, preliminary or final subdivision plat, preliminary or final site plan or zoning with a plan of development was approved by a locality prior to the effective date of this Part shall be considered grandfathered and not to be subject to the requirements of sections 4VAC50-60-63 through 4VAC50-60-66 for those areas that were included in the approval, provided that such proffered or conditional zoning plan, preliminary or final subdivision plat, preliminary or final site plan or zoning with a plan of development (i) provides for a layout, which depicts stormwater management facilities, at the time of approval; and (ii) the resulting land disturbing activity is consistent with the requirements of this Part that were effective at the time of approval. In the event that the proffered or conditional zoning plan, preliminary or final subdivision plat, preliminary or final site plan or zoning with a plan of development is subsequently modified or amended in a manner such that there is no increase over the previously approved plat or plan in the amount of phosphorus leaving the site of the land disturbing activity through stormwater runoff, and such that there is no increase over the previously approved plat or plan in the volume or rate of runoff, the grandfathering shall continue as before.

Committee members agreed to discuss the draft language with their constituents and to provide comments back to Mr. Brown.

Mr. Toalson thanked members for their participation.

Mr. Brown said that he would send out the final draft version to committee members for their review and comments.

Mr. Toalson said that the draft would be presented to the full RAP with the understanding that there was general consensus among the committee.

The meeting was adjourned.

Water Quality Subcommittee

Attendees
Norm Goulet, Chairman
Andrew Gould
Roy Mills
Mike Gerel
Bill Street
Brent Fults
Bill Johnston
Jennifer Johnson
Joe Lerch
Brian Wagner
David Sample
DCR Staff Present: Scott Crafton and Doug Fritz

Observers:
Tricia Dunlap, Nature Conservancy (legal intern)
Michelle Virts, City of Richmond

The meeting opened with the chairman handing out draft water quality criteria language based on the discussion held at the previous meeting. This language was considered a “straw man” document for discussion and further editing, as necessary. This document included a definition of *prior developed land* different from the definition of that term currently in the proposed regulations.

The first order of business was to conclude discussion of basing the water quality requirements on a threshold percentage of impervious cover. This concept is based on the *Impervious Cover Model* developed by the Center for Watershed Protection, as described in an *ASCE Journal* article handed out at the last meeting. The selected impervious cover can be associated mathematically with an average annual load of total phosphorus (TP), which would then become the statewide default TP load limit in the regulations.

The TP load limit proposed in the handout was 0.32 lbs./acre/year, associated with an average watershed impervious cover (IC) of 10%. This is the IC threshold beyond which the *Impervious Cover Model* predicts that stream degradation will occur.

One member suggested, as an alternative, that the IC threshold be set at 12%, which he believes will be more acceptable to the regulated community and would be justified given that the *Impervious Cover Model* recognizes IC *ranges* resulting in degradation, depending upon the presence or absence of other management practices being used in the watershed. He stated his belief that the 10% number will be negotiated to something higher before the regulatory process concludes, and that a threshold of 12% IC would still provide needed protection of streams, but would not be as costly to meet.

The chairman polled the subcommittee members regarding their comfort level with setting the standard at 10% IC. A spirited discussion ensued as each member was polled. One member pointed out that the 10% threshold is actually at the top of the first range, or *transition zone,* in the model and that setting the mark at 12% IC would be less defensible scientifically and would likely result in degradation of the receiving streams. That damage would have to be repaired after the fact, typically at a much higher cost. He felt that setting the threshold at 10% was more likely to result in actual stream protection.

Another member pointed out that 10% IC is the point at which, pretty consistently, he sees degradation of stream biota when he performs biological stream monitoring. He said this is true even where the stream's geomorphology has not yet begun to degrade. So he felt that keeping the 10% threshold was appropriate.

Another member stated that the 10% threshold is likely to be more acceptable to the USEPA, in the context of TMDLs and preventing damage to streams. Several members agreed that it is the task of this subcommittee to propose the most scientifically defensible standards we can agree upon, and that RAP members, SWC Board members, etc. will be the one in a position to negotiate other kinds of practical or policy compromises.

One member noted that the peer-reviewed *ASCE Journal* article had a note inviting further comment/discussion on the article, to be submitted no later than 9/1/2010, the date of this meeting. He asked if DCR staff had checked to see if there were, in fact, any comments submitted and whether those comments supported the article's conclusions or disagreed with them. DCR staff agreed to check into the matter. **[NOTE: DCR's Scott Crafton emailed Tom Schueler regarding this on September 2, 2010. Tom said that he had received no comments as of that date. Scott asked to be kept in the loop regarding any comments/discussion submitted about the article.]**

At the end of this discussion, the chairman polled the group once more and determined that everyone present said they could "live with" the 10% IC threshold/0.32 lbs/acre/year proposal and agreed that it is scientifically defensible. One member asked that DCR staff take care to ensure the scientific documentation travels with the regulatory language, so that higher-level policy makers will understand that the proposed criteria are scientifically defensible.

Scott Crafton of DCR noted that there is a mechanism in the regulatory process guidelines allowing the agency to include documents *incorporated by reference* into the regulations. For example, this language could state that the following:

> New development. The key threshold of imperviousness resulting in impacts to local stream channels is 10% watershed impervious cover, which is the upper limit of the transition zone between "sensitive" (i.e., healthy) streams and "impacted" streams (i.e., exhibiting biological and/or geomorphological degradation). This threshold is based on the *Impervious Cover Model* developed and refined by the Center for Watershed Protection, the latest (2009) version of which is *incorporated by reference into this regulation*. Ten percent watershed imperviousness is associated with a Total Phosphorus (TP) load of 0.32 pounds per acre per year. Therefore, the TP load of new development projects shall not exceed 0.32 pounds per acre per year, as calculated pursuant to 4 VAC 50-60-65, except . . . . **(NOTE: italics are for emphasis herein, not for the actual regulation language. This language should be taken into consideration when word-smithing the proposed Water Quality Requirements language to be submitted to the full Regulatory Advisory Panel.)**

The chairman asked that members tell him of any concerns they maintain through this consensus. Three members expressed the following lingering concerns:

- Drew Gould: The *ASCE Journal* article on the *Impervious Cover Model* still indicates that stream channel response can vary within a range of watershed IC percentages, and that the article does not indicate that precise numbers show consistent predictions.
- Bill Street: However, the 10% threshold is at the upper end of the first range, indicating that degradation is more likely to begin at that point. In order to protect stream systems, the threshold should ideally be set even lower than 10%.
- Joe Lerch: This approach to water quality protection is not a panacea. As is often necessary in regulations, it represents a defensible approximation of reality, but results may vary from project to project.

At this point in the meeting, the chairman asked the group to discuss the redevelopment criteria in the proposed regulations. He first asked if anyone had problems with the definition of *prior developed lands* currently in the proposed regulation language or with the substitute proposed in the handout document.

Doug Fritz of DCR noted that the EPA is in the process of using its residual designation authority to require Clean Water Act permits on existing development based on TMDL reports. For example, the EPA has proposed to require permits for areas of two or more acres of impervious cover in the Charles River, MA. Roy Mills of VDOT said that he preferred the existing definition of *prior developed lands*, which refers to the whole site rather than just the impervious area.

Some concerns were expressed about using somewhat arbitrary standards for redevelopment (i.e., 10% or 20% reductions of the pre-development TP load), rather than more scientifically-based criteria. Others noted that these criteria were developed through much discussion, recognizing that redevelopment is very different from new development, thus necessitating a different kind of standard. These numerical standards were negotiated and most of the stakeholder community was comfortable with them.

Scott Crafton of DCR told the group that Tom Schueler of the Chesapeake Stormwater Network is preparing a Draft Technical Paper on the subject of Redevelopment. The paper should be released in the next couple of weeks for public comment prior to finalizing it. Scott said that in the discussion he heard about this last week, Tom is suggesting that redevelopment sites with very high initial impervious cover (65% - 95% IC) are likely to have great difficulty complying with numerical standards. Tom will suggest that such sites should be allowed to simply comply through application of certain BMPs that can be implemented at such sites. He will also propose a hierarchy of compliance methods for such sites, with offsets as a last resort.

Scott passed out two handouts, one of which listed the kinds of BMPs that Tom suggested might apply. The other had a table of redevelopment requirements for the Bay-region states and a more specific list of Maryland's new redevelopment requirements. These were provided in response to the subcommittee's request to know what other regional states are doing for stormwater management.

One member of the group noted that one critical factor determining the difficulty of compliance at redevelopment sites is whether the original structure(s) is being razed or rehabilitated. He said it is much easier to comply with stormwater management requirements where the structure(s) is being razed, because then the site becomes more like a new development site. He also noted that it is important that any new development standards be applied to only the actual disturbed area of the site. In that regard, if an existing development site is merely being rehabilitated for a different use and no land disturbance occurs, then the general construction permit is not triggered and *no* stormwater management requirements should apply. Following some discussion, it was clear that the group agreed with this.

One member suggested that a site should be eligible to comply with the redevelopment standards *only* if there is no increase – and, even better, a reduction – of impervious cover. He also suggested that, as is required in Maryland, if the redevelopment project results in an increase of impervious cover, then the entire disturbed area should be required to meet the *new development* requirements. He explained his logic, and the group generally agreed with it.

This led to an extended discussion of how different kinds of redevelopment standards might apply to VDOT road projects, where true redevelopment is occurring largely within the existing right-of-way. Roy Mills of VDOT wanted to be clear that for projects where impervious area is being added (e.g., addition of a turn lane, widening the shoulder, etc.), the project would only have to comply with one standard or the other, and not both at the same time (i.e., redevelopment standard applied to the entire project site *plus* the new development standard applied to the disturbed area). After more discussion, the group agreed with his recommendation.

At that point in the meeting (12:15 pm), the chairman called a lunch break and asked the members to return by 1:00 pm. He stated that he and Doug Fritz of DCR would try to capture on paper, in regulatory language format, the ideas the group had expressed, for reaction and further discussion. He stated his goal to complete work on this by the end of the meeting so the group would not need to meet again.

After lunch, someone asked about whether the group had actually reached consensus on two other issues: (1) use of the 90^{th} percentile storm (1-inch rainfall) as the basis for calculating the water quality Treatment Volume, and (2) continuing to include managed turf in the calculation of the composite runoff coefficient for a site. The chairman led a brief discussion and recollection of these matters, with the group agreeing in the end that they were comfortable with the scientific reasoning behind both of these factors.

Discussion then returned to the redevelopment criteria and discussion of the language drafted at lunchtime. One member said he thought the language could be simplified to remove some of the wordiness, which leads to confusion about the meaning. There was much discussion of this. The group finally agreed that the following were the critical concepts:

- If the redevelopment project disturbs less than 1 acre *and* there is *no increase* of total impervious cover, then the project should be required to reduce the pre-development TP load by 10%.
- If the redevelopment project disturbs greater than or equal to 1 acre *and* there is *no increase* of total impervious cover, then the project should be required to reduce the pre-development TP load by 20%.
- *In either case,* if the project results in an increase of the pre-development impervious cover, then *the entire disturbed area* must meet the *new development* criteria.
- VDOT redevelopment projects should have to reduce the pre-development TP load by 20%, regardless of whether they add impervious surface.

There was some additional discussion of this last point, with concerns that where significant new impervious surface were being added, VDOT should have to do more. The example suggested was expanding Interstate 64 between Richmond and Newport News from four lanes to six lanes, which might be accomplished by adding the lanes in the median and not having to purchase additional right-of-way. However, others in the group pointed to the reality of VDOT budgets and noted that such expansion will not occur within the foreseeable future. Furthermore, a number in the group recognized that highway construction has constraints that are fundamentally different from those at conventional building sites and, therefore, they should be provided more leeway. Others suggested that the final concept noted above should apply to any linear redevelopment project (railway construction, power lines, etc.) and not just to highway projects.

At that point, the chairman and Doug Fritz re-drafted the proposed redevelopment language based on the discussion and projected it onto the wall for all to see and discuss. Several members suggested some word-smithing that needed to be done, but all agreed that conceptually that language reflected the discussion and all agreed to support it.

The chairman then asked once again if the *everyone* in the group agreed that they would support the draft water quality criteria language that all had discussed and reviewed during the two meetings, as it is passed up to the Regulatory Advisory Committee for their meeting on September 15th. Everyone agreed that they supported the proposed language, as discussed and reviewed. In that regard, one member requested that if any stakeholder organization unearths research or opinions with scientific support that are different from or in opposition to what this subcommittee has agreed upon, these things should be submitted and discussed within the context of the public participation process so they can be considered openly for the public record, and not vetted behind closed doors or as last-minute surprises. He said he felt that this kind of maneuvering was responsible for the last minute confusion and concerns raised by legislators this past fall, resulting in the temporary suspension of the regulatory process. He said that we need to move forward with these regulations, working together in good faith toward a set of requirements that can be broadly supported.

With that, the chairman adjourned the meeting.

Enclosures: Handout #1: Draft water quality criteria for discussion
Handout #2: Redevelopment requirements of Bay-region states
Handout #3: New Maryland redevelopment requirements
Handout #4: Redevelopment factoids from the Chesapeake Stormwater Network
Draft substitute redevelopment language (resulting from meeting discussion)
Tom Schueler’s *ASCE Journal* article on the Impervious Cover Model (for internal DCR staff use: potential incorporation by reference in regulations)

HANDOUT #1:
PROPOSED WATER QUALITY LANGUAGE FOR CONSIDERATION/REACTION

4VAC50-60-10. Definitions.

"Prior developed lands" means any existing impervious cover at the time of predevelopment.

4VAC50-60-53. General requirements.

The physical, chemical, biological, and hydrologic characteristics and the water quality and quantity of the receiving state waters shall be maintained, protected, or improved in accordance with the requirements of this part. Objectives include, but are not limited to, supporting state designated uses and water quality standards and the antidegradation of existing stream conditions. All control measures used shall be employed in a manner that minimizes impacts on receiving state waters.

4VAC50-60-56. Applicability of other laws and regulations.

Nothing in this chapter shall be construed as limiting the applicability of other laws and regulations, including, but not limited to, the Virginia Stormwater Management Act, Virginia Erosion and Sediment Control Law, and the Chesapeake Bay Preservation Act, except as provided in § 10.1-603.3 I of the Code of Virginia and all applicable regulations adopted in accordance with those laws, or the rights of other federal agencies, state agencies, or local governments to impose more stringent technical criteria or other requirements as allowed by law.

4VAC50-60-63. Water quality design criteria requirements.

In order to protect the quality of state waters and to control the discharge of stormwater pollutants from regulated activities, the following minimum design criteria and statewide standards for stormwater management shall be applied to the site of a construction activity.

1. New development. The total phosphorus load of new development projects shall not exceed 0.32 pounds per acre per year, as calculated pursuant to 4VAC50-60-65, except:

2. Development on prior developed lands.

    a. The total phosphorus load of a project occurring on prior developed lands and disturbing greater than or equal to 1 acre where there is no increase in impervious cover shall be reduced at least 20% below the predevelopment total phosphorus load.

    b. The total phosphorus load of a project occurring on prior developed lands and disturbing less than 1 acres where there is no increase in impervious cover shall be reduced to an amount at least 10% below the predevelopment total phosphorus load.

    c. The total phosphorus load of a project occurring on prior developed lands where the final impervious cover is increased over the predevelopment condition, shall be designed in accordance with the new development criteria for all disturbed acreage.

d. In lieu of (C.) the total phosphorus load of a linear development project occurring on prior developed lands may be reduced 20%.

e. The total phosphorus load shall not be required to be reduced to below the applicable standard for new development unless a more stringent standard has been established by a qualifying local program.

3. Compliance with subdivisions 1 and 2 of this section shall be determined in accordance with 4VAC50-60-65

4. TMDL. In addition to the above requirements, if a specific WLA for a pollutant has been established in a TMDL and is assigned to stormwater discharges from a construction activity, necessary control measures must be implemented by the operator to meet the WLA in accordance with the requirements established in the General Permit for Discharges of Stormwater from Construction Activities or an individual permit, which address both construction and post construction discharges.

5. Chesapeake Bay. Upon the completion of the Virginia TMDL Implementation Plan for the Chesapeake Bay Nutrient and Sediment TMDL approved by EPA, the board shall by regulatory action establish a water quality design criteria for new development activities that is consistent with the pollutant loadings called for in the approved Watershed Implementation Plan.

6. Nothing in this section shall prohibit a qualifying local program from establishing a more stringent standard.

4VAC50-60-65. Water quality compliance.

A. Compliance with the water quality design criteria set out in subdivisions 1 and 2 of 4VAC50-60-63 shall be determined by utilizing the Virginia Runoff Reduction Method or another equivalent methodology that has been approved by the board.

B. The BMPs listed on the Virginia Stormwater BMP Clearinghouse website shall be utilized as necessary to effectively reduce the phosphorus load in accordance with the Virginia Runoff Reduction Method. Design specifications for the BMPs can be found on the Virginia Stormwater BMP Clearinghouse Website

D. A qualifying local program may establish limitations on the use of specific BMPs following the submission of the proposed limitation and written justification to the department.

E. Where the land-disturbing activity only occurs on a portion of the site, the local program may review the stormwater management plan based upon the portion of the site that is proposed to be developed, provided that the local program has established guidance for such a review. Such portion shall be deemed to include any area left undeveloped pursuant to any local requirement or proffer accepted by a locality. Any such guidance shall be provided to the department.

F. The local program shall have the discretion to allow for application of the criteria to each drainage area of the site. However, where a site drains to more than one HUC, the pollutant load reduction requirements shall be applied independently within each HUC unless reductions are achieved in accordance with a comprehensive watershed stormwater management plan in accordance with 4VAC50-60-92.

G. Offsite alternatives where allowed in accordance with 4VAC50-60-69 may be utilized to meet the design criteria of subdivisions 1 and 2 of 4VAC50-60-63.

HANDOUT #2:

Redevelopment Stormwater Requirements in the Chesapeake Bay Watershed				
Jurisdiction	**Redevelopment Requirement**	**Min. Area (sf)**	**Offset?**	**Status**
Maryland	Reduce IC by 50% or Reduce/Treat Runoff Volume from ½ inch rainfall event	5000	Yes	2010
Virginia	Reduce existing phosphorus load by 10 to 20% depending on redevelopment site area	10,000	Yes	2011
West Virginia	Reduce runoff volume from one inch rainfall event, less redevelopment credits	43,560	Yes*	2009
District of Columbia	Reduce or Treat Runoff Volume from 1 inch rainfall event	250	Yes	2010?
New York	New IC: Reduce or Treat Runoff Volume from 1 inch rainfall event. Existing IC: Reduce by 25% through IC reduction, BMPs or alternative practices	10,000	Yes	2011
Pennsylvania	20% WQ treatment for the site	10,000	?	2009
Federal	Reduce Runoff Volume from 95th percentile rainfall event (1.5 to 1.9 inches in watershed)	5000	No?	2010
Philadelphia	Reduce or Treat Runoff Volume from 1 inch rainfall event	5000	Yes	2008

HANDOUT #3:

New Maryland Redevelopment Requirements for Stormwater Management

- Redevelopment is defined as a prior developed site ***with at least 40% impervious area***. Any site with less than 40% imperviousness, whether new or previously developed, must meet the *new development* criteria.
- *New development* criteria also apply if the area of impervious cover is increased to more than previously existed on the site.
- The redevelopment criteria apply to the disturbed area of the project site, not the entire site.
- Options: may reduce imperviousness by 50% or treat the runoff
- The use of "Green Technology" (referred to as Environmental Site Design, or ESD) is ***required***.
- The developer may use offsets only as a last resort; he must accomplish some treatment or IC reduction on the redevelopment site itself:
  - A combination of ESD and an on-site or off-site BMP
  - Retrofitting (BMP upgrades, filtering practices, off-site ESD)
  - Participation in a stream restoration project
  - Pollution (sic nutrient) trading
  - Payment of a fee-in-lieu
  - Locality granting a partial waiver

Design Implications

- Redevelopment sites with less than 40% IC are sized using the full *new development* criteria.
- There is a strong incentive to sharply reduce IC on redevelopment sites, although this may be at odds with urban density objectives.
- There is a strong stormwater "penalty" for large increases in IC at redevelopment sites.

For reference, Virginia's SWM Reg definition of *redevelopment*:

"*Prior developed lands*" means land that has been previously utilized for residential commercial, industrial, institutional, recreation, transportation or utility facilities or structures, and that will have the impervious areas associated with those uses altered during a land-disturbing activity.

HANDOUT #4: REDEVELOPMENT FACTOIDS

Why Redevelopment Is So Hard

- Many projects are quite small
- Many cities traditionally waive redevelopment projects
- Lack of space and/or high cost of land
- Constrained by inverts of existing storm drains
- Conflicts with existing underground utilities
- Compacted and polluted soils
- Traditional and even some new stormwater ESD practices developed in suburban areas don’t work well in our cities
- Designers have little or no experience in designing the practices that do work
- Most sites discharge to impaired waters subject to TMDLs
- Natural stream network altered or eliminated
- Underground treatment is very expensive
- Full compliance cannot be achieved at many sites
- Higher cost of compliance than in greenfield settings
- Conflicts with Smart Growth objectives of land use efficiency
- Surface practices could result in loss of development intensity
- OTHERS?

Why Redevelopment Is So Important

- It can incrementally reduce untreated pollution from existing development
- It can support the Green Building and Green Infrastructure movements
- It can support the concept of Sustainable Cities
- It can contribute to the abatement of combined sewer overflows

Expected Redevelopment Share of Future Development

- About 2 million acres of existing IC in the Bay watershed
- 42% of urban land is expected to be redeveloped by 2030
- There has been a sharp increase in growth in core cities and inner suburbs in Bay watershed cities in the last 5 years
- Sprawl seems to be slowing a bit in this economy

Sustainable Stormwater Practices for the City

- Impervious cover removal
- Urban tree planting (MDE gives a credit of 100 sq. ft. IC removal per street tree (200 sq. ft. if soil restoration is included)
- Vegetated roofs
- Rainwater harvesting
- Permeable pavement
- Bioretention
- Expanded tree pits
- Foundation planters
- Green streets
- Sand filters

HANDOUT #5: PROPOSED SWM REG REDEVELOPMENT CRITERIA

4 VAC 50-60-63. Water quality design criteria requirements.
In order to protect the quality of state waters and to control the discharge of stormwater pollutants from regulated activities, the following minimum design criteria and statewide standards for stormwater management shall be applied to the site of a construction activity.

1. New development. The total phosphorus load of new development projects shall not exceed 0.32 pounds per acre per year, as calculated pursuant to 4VAC50-60-65, except:

2. Development on prior developed lands.

a. The total phosphorus load of a project occurring on prior developed lands that disturbs less than one acre where the final impervious cover is equal to or less than that of the predevelopment condition shall be reduced 10%

b. The total phosphorus load of a project occurring on prior developed lands that disturbs greater than one acre where the final impervious cover is less than that of the predevelopment condition shall be reduced 20%.

c. The total phosphorus load of a project occurring on prior developed lands that disturbs less than or equal to one acre where the final impervious cover is greater than the predevelopment condition shall be reduced 10% and any increase in impervious cover shall be designed in accordance to the new development design criteria.

d. The total phosphorus load of a project occurring on prior developed lands that disturbs greater than one acre where the final impervious cover is greater than the predevelopment condition shall be reduced 20% and any increase in impervious cover shall be designed in accordance to the new development design criteria.

e. The total phosphorus load of a linear project occurring on prior developed lands that shall be reduced 20%.

f. The total phosphorus load shall not be required to be reduced to below the applicable standard for new development unless a more stringent standard has been established by a qualifying local program.

[NOTE: The group agreed that these criteria need to be word-smithed prior to submitting them to the full Regulatory Advisory Panel – see the Meeting Minutes for more detail.]

Is Impervious Cover Still Important? Review of Recent Research

Thomas R. Schueler[1]; Lisa Fraley-McNeal[2]; and Karen Cappiella[3]

Abstract: The impervious cover model (ICM) has attracted considerable attention in recent years, with nearly 250 research studies testing its basic hypothesis that the behavior of urban stream indicators can be predicted on the basis of the percent impervious cover in their contributing subwatershed. The writers conducted a meta-analysis of 65 new research studies that bear on the ICM to determine the degree to which they met the assumptions of the ICM and supported or did not support its primary predictions. Results show that the majority of research published since 2003 has confirmed or reinforced the basic premise of the ICM, but has also revealed important caveats and limitations to its application. A reformulated conceptual impervious cover model is presented in this paper that is strengthened to reflect the most recent science and simplify it for watershed managers and policy makers. A future challenge is to test the hypothesis that widespread application of multiple management practices at the catchment level can improve the urban stream degradation gradient that has been repeatedly observed by researchers across the country.

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CE Database subject headings: Streams; Urban areas; Urban development; Watersheds.

Introduction

Impervious cover (IC) has unique properties as a watershed metric in that it can be measured, tracked, forecasted, managed, priced, regulated, mitigated, and, in some cases, even traded. In addition, IC is a common currency that is understood and applied by watershed planners, storm-water engineers, water quality regulators, economists, and stream ecologists alike. IC can be accurately measured using either remote sensing or aerial photography (Goetz et al. 2003; Jantz et al. 2005). IC is also strongly correlated with individual land use and zoning categories (Cappiella and Brown 2001; Slonecker and Tilley 2004), which allows planners to reliably forecast how it changes over time in response to future development. Consequently, watershed planners rely on IC (and other metrics) to predict changes in stream health as a consequence of future development (CWP 1998).

Schueler (2004) has utilized IC to classify and manage urban streams, and economists routinely use IC to set rates for storm-water utilities and off-site mitigation (Parikh et al. 2005). Engineers utilize IC as a key input variable to predict future downstream hydrology and design storm-water management practices (MSSC 2005). A number of localities have modified their zoning to establish site-based or watershed-based IC caps to protect streams or drinking water supplies. In recent years, IC has been used as a surrogate measure to ensure compliance with water quality standards in impaired urban waters (Bellucci 2007).

Another noteworthy aspect of IC has been its use as an index of the rapid growth in land development or sprawl at the watershed, regional, and national scale. For example, Jantz et al. (2005) found that IC increased at a rate five times faster than population growth between 1990 and 2000 in the Chesapeake Bay watershed. At a national level, several recent estimates of IC creation underscore the dramatic changes in many of our nation's watersheds as a result of recent or future growth. Elvidge et al. (2004) estimated that about 112,665 km^2 (43,500 mi^2) of IC had been created in the lower 48 states as of 2000. Forecasts by Beach (2002) indicate that IC may nearly double by the year 2025 to about 213,837 km^2 (82,563 mi^2), given current development trends. Although care must be taken when extrapolating from national estimates, it is clear that several hundred thousand stream miles are potentially at risk. For example, a detailed GIS analysis by Exum et al. (2006) indicates that 14% of the total watershed area in eight southeastern states had exceeded 5% IC as of 2000.

Given growth in IC, watershed managers are keenly interested in the relationship between subwatershed IC and various indicators of stream quality. The impervious cover model (ICM) was first proposed by Schueler (1994) as a management tool to diagnose the severity of future stream problems in urban subwatersheds. The ICM projects that hydrological, habitat, water quality, and biotic indicators of stream health decline at around 10% total IC in small (i.e., 5 to 50 km^2) subwatersheds (CWP 2003). The ICM defines four categories of urban streams based on how much IC exists in their contributing subwatershed: *sensitive, impacted, nonsupporting,* and *urban drainage* (Schueler 1994) (Fig. 1). The ICM also outlines specific quantitative or narrative predictions for stream indicators within each stream category to define the severity of current stream impacts and the prospects for their future restoration (Schueler 2004).

The general predictions of the ICM are as follows: streams with less than 10% subwatershed IC continue to function as *sensitive streams*, and are generally able to retain their hydrologic

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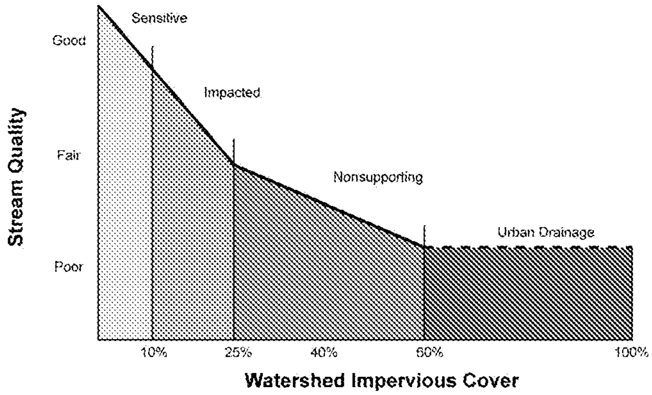

Fig. 1. Impervious cover model [adapted from CWP (1998)]

function and support good to excellent aquatic diversity. Streams with 10 to 25% subwatershed IC behave as *impacted streams* and show clear signs of declining stream health. Most stream health indicators fall in the fair range, although some reaches with extensive riparian cover may score higher. Streams that possess between 25 and 60% subwatershed IC are classified as *nonsupporting*, as they no longer support their designated uses in terms of hydrology, channel stability, habitat, water quality, or biological diversity. Nonsupporting streams become so degraded that it may be difficult or impossible to fully recover predevelopment stream function and diversity. Streams within subwatersheds exceeding 60% IC are often so extensively modified that they merely function as a conduit for flood waters. These streams are classified as *urban drainage* and consistently have poor water quality, highly unstable channels, and very poor habitat and biodiversity scores. In many cases, these urban streams are eliminated altogether by earthworks and/or storm drain enclosure.

The ICM has been extensively tested in ecoregions around the U.S. and elsewhere with more than 250 different reports reinforcing the basic model for single stream indicators or groups of stream indicators (CWP 2003; Schueler 2004). It should be noted, however, that only a third of these reports were published in peer-reviewed journals. For the purposes of this paper, we reviewed new research efforts that have further explored the ICM relationship. The methods used to conduct this review are described in the following section.

Methods

The writers conducted a meta-analysis of 65 new research studies that bear on the ICM and were not included in the papers and reports originally analyzed by CWP (2003). Each paper was reviewed to determine the number of streams, average drainage area, range in urbanization of study subwatersheds, and the receiving water indicator(s) sampled. A database was created to compile this information and four criteria were used to determine whether a paper was suitable for inclusion. First, a minimum of 10 individual subwatersheds must have been sampled. Second, riverine studies that sampled several stations in a progressive downstream direction in the same watershed were omitted. Third, only studies that directly measured impervious cover or an autocorrelated metric, such as % urban land or an urban intensity index (Meador et al. 2005), were included in the database. Fourth, the study must have been published in a peer-reviewed, reliable source, such as a scientific journal article or federal report.

Based on these criteria, 30 studies were excluded from the analysis, which yielded a total of 35 papers: 25 from peer-reviewed journals, four from the U.S. Geological Survey, five from peer-reviewed conference proceedings, and one from a state research institute. When researchers sampled multiple indicators, these were considered as separate entries only if they measured more than one major indicator group (e.g., water quality, biological diversity, geomorphology, hydrology, habitat). Multiple measures within the same indicator group were considered a single entry (i.e., sediment, nitrogen, and chloride within the water quality group). As a result, the final ICM database contained 61 individual entries. The complete database is maintained by CWP and is available upon request.

Each paper was then evaluated to determine the degree to which it met the assumptions of the ICM and supported or did not support its primary predictions, resulting in entries being sorted into four categories:

1. *Confirming papers* met the following criteria:
   a. Primarily sampled small subwatersheds (5 to 50 km^2);
   b. Directly estimated impervious cover;
   c. Tested subwatersheds over a broad range of IC;
   d. Reported a strong linear negative relationship for the indicator with increasing IC; and
   e. Showed an initial detectable shift in indicator quality in the 5 to 15% IC range.
2. *Reinforcing papers* either did not meet criteria 1a and 1c described above OR relied on percent urban land or an urban index in lieu of IC. These studies demonstrated a strong linear negative relationship between the indicator and the metric used to describe urbanization.
3. *Inconclusive papers* were defined as studies that met most of criteria 1a though 1c described for confirming papers but reported a mixed, weak, or inconsistent relationship between indicator quality and the metric used to describe urbanization.
4. *Contradicting* papers met most of criteria 1a through 1c described for confirming papers but did not show a negative or detectable relationship between urbanization and the indicator category analyzed.

General Findings from the Database

The geographic scope and intensity of recent research related to the ICM model has been impressive. Sampling has been conducted in more than 2,500 subwatersheds located in 25 states for more than 35 different indicators of environmental quality. Most studies focused on various indicators of freshwater stream quality (75%), but an increasing number explored the ICM relationship in tidal waters (25%). The majority of research has been conducted on the East Coast, with a strong emphasis on the piedmont and coastal plain regions. Much less attention has been focused along the Northern Tier, Rocky Mountains, and arid Southwest, although the Pacific Northwest was well represented.

Three additional factors complicated the comparison of individual studies. First, researchers relied on many different metrics to characterize urbanization including IC, % urban land, % developed land, and an urban intensity index, among others. Although most of these metrics are autocorrelated, some are less accurate or more variable than others (e.g., % urban land or developed land). Second, researchers applied a wide range of different statistical methods and transformations to analyze their watershed data. While it is outside the scope of this paper to critically evaluate

Table 1. Overall Summary of Recent ICM Research Included in ICM Database[a]

Confirming	Reinforcing	Inconclusive	Contradicting	Total
19	23	9	10	61

[a]For definitions, see "Methods" section.

these methods, we acknowledge that this may have caused researchers to draw different statistical inferences from the same data. Third, the geographic scale at which subwatersheds were sampled varied greatly. While most studies conformed to headwater ICM assumptions (e.g., subwatershed area ranging from 5 to 50 km^2), several regional studies had a mean subwatershed area as large as 75 to 150 km^2, which lies beyond the predictive power of the ICM (CWP 2003). An overall summary of the ICM research is provided in Table 1, and more specific results for individual indicators in freshwater and tidal ecosystems are provided in Tables 2 and 3.

The following general findings were drawn from the ICM research review, with the caveat that they may not fully apply to every ecoregion or watershed condition. Nearly 69% (this number was not tested for statistical significance due to the limited number of studies in the database) of studies confirm or reinforce the ICM, which suggests it is a robust indicator of stream quality when applied properly. On the other hand, IC does not appear to be the best metric to predict stream quality indicators below 10% subwatershed IC. Other metrics, such as subwatershed forest cover, riparian forest cover, road density, or crop cover may be more useful in explaining the variability within sensitive subwatersheds.

The average IC at which stream degradation was first detected was about 7% (range of 2–15%), depending on the indicator and ecoregion. There appears to be some evidence that lower IC thresholds are associated with extensive predevelopment forest or natural vegetative cover present in the subwatershed (Ourso and Frenzel 2003). By contrast, higher initial thresholds appear to be associated with extensive prior cultivation or range management in a subwatershed or region (Cuffney et al. 2005). Researchers who evaluated a second threshold concluded that many stream indicators consistently shifted to a poor condition at about 20 to 25% subwatershed IC. Each study was reviewed to identify the maximum subwatershed IC that was sampled. However, many of the studies focused on suburban or urbanizing subwatersheds, and did not sample the full range of possible IC within the study area.

Table 2. Distribution of Database Entries with regard to Freshwater Streams

Indicator	Total	Confirming	Reinforcing	Inconclusive	Contradicting
Hydrology[a]	4	0	0	1 (Poff et al. 2006)	3 (Coles et al. 2004; Fitzpatrick et al. 2005; Sprague et al. 2006)
Geomorphology	3	2 (Cianfrani et al. 2006; Coleman et al. 2005)	0	1 (Short et al. 2005)	0
Habitat	6	2 (Ourso et al. 2003; Schiff and Benoit 2007)	1 (Snyder et al. 2003)	0	3 (Coles et al. 2004; Fitzpatrick et al. 2005; Sprague et al. 2006)
Water quality[b]	6	3 (Ourso et al. 2003; Schiff and Benoit 2007; Schoonover and Lockaby 2006)	0	2 (Coles et al. 2004; Sprague et al. 2007)	1 (Sprague et al. 2006)
Benthic macros	10	4 (Alberti et al. 2006; Ourso et al. 2003; Schiff and Benoit 2007; Walsh 2004)	5 (Coles et al. 2004; Cuffney et al.2005; Kratzer et al. 2006; Walsh et al.2001; Moore and Palmer 2005)	0	1 (Sprague et al. 2006)
Fish	9	0	7 (Fitzpatrick et al. 2005; Meador et al.2005; Miltner et al. 2004; Moore and Plamer 2005; Roy et al.2006a,b; Snyder et al. 2003)	1 (Coles et al. 2004)	1 (Sprague et al. 2006)
Composite[c]	1	1 (Goetz et al. 2003)	0	0	0
Other[d]	5	1 (Ourso and Frenzel 2003)	1 (Riley et al. 2005)	2 (Coles et al. 2004; Potapova et al. 2005)	1 (Sprague et al. 2006)

Note: $n=44$.

[a]Primarily baseflow.

[b]Primarily water quality parameters sampled during dry weather; no studies evaluated storm-flow quality.

[c]Combined index measuring habitat, benthic macroinvertebrates, and fish.

[d]Other includes sediment quality, algae, and amphibian abundance.

Table 3. Distribution of Database Entries with regard to Small Estuaries

Indicator	Total	Confirming	Reinforcing	Inconclusive	Contradicting
Water quality[a]	4	1 (Holland et al. 2004)	2 (Deacon et al. 2005; Xian et al. 2007)	1 (King et al. 2005)	0
Sediment quality	3	1 (Holland et al. 2004)	1 (Paul et al. 2002)	1 (Comeleo et al. 1996)	0
Benthic macros	5	1 (Holland et al. 2004)	4 (Bilkovic et al. 2006; Deacon et al. 2005; Hale et al. 2004; King et al. 2005)	0	0
Fish	3	1 (Holland et al. 2004)	2 (Hale et al. 2004; King et al. 2004)	0	0
Other[b]	2	2 (Holland et al. 2004)[c]	0	0	0

Note: $n=17$.

[a]Ambient water quality usually measured in dry weather.

[b]Other includes hydrology and shrimp.

[c]Both confirming entries were for the reference Holland et al. (2004); one was for hydrology and the other for shrimp.

Further testing is required to identify the IC% at which natural stream channels disappear from the urban landscape and are replaced by pipes, channels, and other forms of storm-water infrastructure.

Three papers accounted for the majority of contradicting entries (Sprague et al. 2006; Fitzpatrick et al. 2005; Coles et al. 2004). It should be noted that each study had a mean subwatershed drainage area ranging from 75 to 100 km^2. In each case, the authors also cited a "legacy effect," including historical stream corridor disturbance and current water regulation in the front range watersheds; dams, impoundments, and wetland complexes in the New Hampshire seacoast region; and watershed and soil effects of glaciation on midwest watersheds.

Few studies examined hydrological indicators, and the results were generally contradicting or ambiguous (Table 2). In particular, the inverse relationship between subwatershed IC and stream baseflow was not found to be universal, as nontarget irrigation and leakage from existing water infrastructure appeared to increase baseflow in many urban watersheds, regardless of IC. None of the studies reviewed directly measured the relationship between IC and increased storm-water runoff, although a recent review by Shuster et al. (2005) provides numerous case studies where this relationship was very strong. Researchers that have relied on existing USGS hydrologic gages are often hindered by the generally large subwatershed areas they serve [mean 90 km^2—Poff et al. (2006)].

In general, researchers found the ICM to be an initial but not final predictor of individual stream geomorphology variables, when drainage area and stream slope were properly controlled for [Table 2 and Cianfrani et al. (2006)]. IC was frequently found to be related to aggregate measures of stream habitat, although instream and riparian habitat components may behave differently within the same stream reach. Most habitat metrics were initially sensitive to IC in the 5 to 20% range but exhibited a nonlinear habitat response thereafter (which suggests that habitat metrics may not be well calibrated for highly urban streams).

Researchers also reported inconsistent relationships between IC and dry weather water quality. While differences between urban and nonurban sites were frequently noted, there was seldom a linear trend with increasing subwatershed IC. The relationship between IC and storm-water quality would be expected to be strong, but no researchers in this review had simultaneously sampled a large population of storms and subwatersheds. A national review of nearly 8,000 urban storm events compiled by Pitt et al. (2004) indicates event mean concentrations of 20 storm-water pollutants statistically were more closely related to urban land use and regional and first flush effects than impervious cover per se. One study of various pollutants in the Tampa Bay watershed found that the load of storm-water pollutants delivered, however, is still strongly dominated by subwatershed IC (Xian et al. 2007).

Benthic macroinvertebrates appeared to conform to the ICM more than any other stream indicator (Table 2). More than 90% of the studies directly supported or generally reinforced the ICM. Researchers generally found a strong negative relationship between fish IBI scores and subwatershed IC, but there were also confounding effects due to differences in stream slope, type, or subwatershed size (Walters et al. 2003; Wang et al. 2003) or the degree of prior headwater stream alteration (Morgan and Cushman 2005).

Several researchers have recently examined whether the ICM applies to tidal coves and small estuaries (see Table 3). Holland et al. (2004) indicate that adverse changes in physical, sediment, and water quality variables can be detected at 10 to 20% subwatershed IC, with stronger biological responses observed between 20 and 30% IC. The primary physical changes involve greater salinity fluctuations, sedimentation, and sediment contamination. The biological response includes declines in benthic macroinvertebrates, shrimp, and finfish diversity. Although none of the studies in the database examined algal blooms as an indicator in tidal coves and small estuaries, a study by Mallin et al. (2004) found that algal blooms and anoxia resulting from nutrient enrichment by storm-water runoff also are routinely noted at about 10 to 20% subwatershed IC.

Approximately 25% of the papers reviewed explored the effect of riparian conditions on the ICM. The studies that evaluated this relationship showed a consistent riparian effect, generally manifested as (1) a decline in the quality and extent of cover in the riparian network as subwatershed IC increases; (2) little or no statistical difference in the proportion of forest cover found in the riparian zone and the subwatershed as a whole; and (3) generally higher habitat and biological scores for streams with extensive riparian cover or palustrine wetland complexes. Riparian forest cover appears to be an important factor in maintaining stream geomorphology and various indexes of biotic integrity. As a group, the studies suggest that stream indicator values increase when riparian forest cover is retained over at least 50 to 75% of the length of the upstream network (Moore and Palmer 2005; Goetz et al. 2003; Wang et al. 2003).

The beneficial impact of riparian forest cover appears to diminish as subwatershed IC increases (Roy et al. 2005, 2006a; Walsh et al. 2007; Goetz et al. 2003). At a certain point [15% urban land as identified by Roy et al. (2006a) or 10% IC as identified by Goetz et al. (2003)], the degradation caused by upland storm-water runoff shortcutting the buffer overwhelms the more localized benefits of riparian canopy cover. A study by McBride and Booth (2005) was not included in the database, but found that downstream improvements in some stream quality indicators may still be observed when an unforested stream segment flows into a long segment of extensive riparian forest or wetland cover.

The issue as to whether watershed treatment (i.e., storm-water treatment practices, buffers, land conservation) can prevent the stream impacts forecasted by the ICM is largely unresolved. The recent literature is largely silent on this topic, with the exception of the riparian buffer research noted earlier. It is worth noting that most regions where the ICM has been tested have had some degree of storm water, buffer, or land development regulations in place for several decades (e.g., MD, VA, NC, WA, GA), although the extent or effectiveness of watershed treatment has seldom been measured and is often incomplete.

Discussion: Reformulated ICM

While this review has found that 69% of peer-reviewed papers generally support or reinforce the original ICM, it has also revealed ways the ICM can be strengthened to reflect the most recent science and simplify it for watershed managers and policy makers. A reformulated version of the ICM is presented in Fig. 2. Fig. 2 is a conceptual model that illustrates the relationship between watershed impervious cover and the stream hydrologic, physical, chemical, and biological responses to this disturbance. The model is intended to predict the average behavior of this group of indicator responses over a range of IC, rather than predicting the precise score of an individual indicator. Based on the response, streams fall into the sensitive, impacted, nonsupporting, or urban drainage management categories, whose boundaries represent a compilation of different approaches to interpret stream condition (e.g., research studies that evaluate the same stream quality indicator may have similar quantitative outcomes that represent different qualitative conditions depending on the approach used).

The reformulated ICM includes three important changes to the original conceptual model proposed by Schueler (1994). First, the IC/stream quality relationship is no longer expressed as a straight line, but rather as a "cone" that is widest at lower levels of IC and progressively narrows at higher IC. The cone represents the observed variability in the response of stream indicators to urban disturbance and also the typical range in expected improvement that could be attributed to subwatershed treatment. In addition, the use of a cone rather than a line is consistent with the findings that exact, sharply defined IC thresholds are rare, and that most

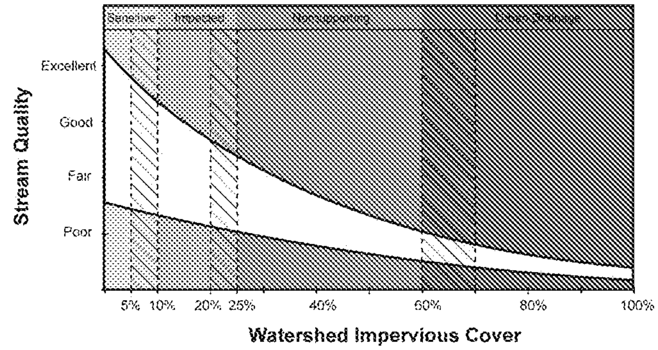

Fig. 2. Reformulated impervious cover model

regions show a generally continuous but variable gradient of stream degradation as IC increases.

Second, the cone width is greatest for IC values less than 10%, which reflects the wide variability in stream indicator scores observed for this range of streams. This modification prevents the misperception that streams with low subwatershed IC will automatically possess good or excellent quality. As noted earlier, the expected quality of streams in this range of IC is generally influenced more by other watershed metrics such as forest cover, road density, riparian continuity, and cropping practices. This modification suggests that IC should not be the sole metric used to predict stream quality when subwatershed IC is very low.

Third, the reformulated ICM now expresses the transition between stream quality classifications as a band rather than a fixed line (e.g., 5 to 10% IC for the transition from sensitive to impacted, 20 to 25% IC for the transition from impacted to nonsupporting, and 60 to 70% IC for the transition from nonsupporting to urban drainage). The band reflects the variability in the relationship between stream hydrologic, physical, chemical, and biological responses and the qualitative endpoints that determine stream quality classifications. It also suggests a watershed manager's choice for a specific threshold value to discriminate among stream categories should be based on actual monitoring data for their ecoregion, the stream indicators of greatest concern and the predominant predevelopment regional land cover (e.g., crops or forest).

The ICM is similar to other models that describe ecological response to stressors from urbanization in that the stream quality classifications are value judgments relative to some endpoint defined by society (e.g., water quality criteria). The ICM differs from most other models in that it provides a broader focus on a group of stream responses, yet focuses on only one stressor, impervious cover. The focus on IC allows watershed managers to use the ICM both to predict stream response and to manage future impacts by measuring and managing IC.

This review also has identified several important caveats to keep in mind to properly apply and interpret the ICM in a watershed context. The first caveat is that watershed scale matters, and that use of the ICM should generally be restricted to first to third order alluvial streams. The second caveat is that the ICM may not work well in subwatersheds with major point sources of pollutant discharge, or extensive impoundments or dams located within the stream network. The third caveat is that the ICM is best applied to subwatersheds located within the same physiographic region. In particular, stream slope, as measured from the top to the bottom of the subwatershed, should be in the same general range for all subwatersheds (Morgan and Cushman 2005; Snyder et al. 2003; Fitzpatrick et al. 2005). The last caveat is that the ICM is unreliable when subwatershed management practices are poor, particularly when IC levels are low (e.g., deforestation, acid mine drainage, intensive row crops, denudation of riparian cover). When these caveats are applied, the available science generally reinforces the validity of the ICM as a watershed planning tool to forecast the general response of freshwater and tidal streams as a result of future land development.

Conclusions

The reformulated ICM organizes and simplifies a great deal of complex stream science into a model that can be readily understood by watershed planners, storm-water engineers, water quality regulators, economists, and policy makers. More information is needed to extend the ICM as a method to classify and manage small urban watersheds and organize the optimum combination of best management practices to protect or restore streams within each subwatershed classification.

The challenge for scientists and watershed managers is no longer proving the hypothesis that increasing levels of land development will degrade stream quality along a reasonably predictable gradient—the majority of studies now support the ICM. Rather, researchers may shift to testing a hypothesis that widespread application of multiple management practices at the catchment level can improve the urban stream degradation gradient that has been repeatedly observed. The urgency for testing the catchment effect of implementing best management practices is underscored by the rapid and inexorable growth in IC across the country.

Appendix

The following references, Alberti et al. (2006), Bilkovic et al. (2006), Cianfrani et al. (2006), Coleman et al. (2005), Coles et al. (2004), Comelo et al. (1996), Cuffney et al. (2005), Deacon et al. (2005), Fitzpatrick et al. (2005), Goetz et al. (2003), Hale et al. (2004), Holland et al. (2004), King et al. (2004, 2005), Kratzer et al. (2006), Meador et al. (2005), Miltner et al. (2004), Moore and Palmer (2005), Morgan and Cushman (2005), Ourso and Frenzel (2003), Paul et al. (2002), Poff et al. (2006), Potapova et al. (2005), Riley et al. (2005), Roy et al. (2006a,b), Schiff and Benoit (2007), Schoonover et al. (2006), Short et al. (2005), Snyder et al. (2003), Sprague et al. (2006, 2007), Walsh (2004), Walsh et al. (2001), and Xian et al. (2007), denote research papers that were included in the ICM database. A list of additional papers that were reviewed, but did not meet the criteria for inclusion in the ICM database, is available upon request from the Center for Watershed Protection.

References

Alberti, M., et al. (2006). "The impact of urban patterns on aquatic ecosystems: An empirical analysis in Puget lowland sub-basins." *Landsc. Urban Plann.*, 80(4), 345–361.

Beach, D. (2002.) "Coastal sprawl. The effects of urban design on aquatic ecosystems in the United States." Pew Oceans Commission, Arlington, Va.

Bellucci, C. (2007.) "Stormwater and aquatic life: Making the connection between impervious cover and aquatic life impairments for TMDL development in Connecticut streams." *Proc., TMDL 2007*, 1003–1018.

Bilkovic, D. M., Roggero, M., Hershner, C. H., and Havens, K. H. (2006.) "Influence of land use on macrobenthic communities in nearshore estuarine habitats." *Estuaries and Coasts*, 29(6B), 1185–1195.

Cappiella, K., and Brown, K. (2001). *Impervious cover and land use in the Chesapeake Bay*, Center for Watershed Protection, Ellicott City, Md.

Center for Watershed Protection (CWP). (1998). *Rapid watershed planning handbook*, CWP, Ellicott City, Md.

Center for Watershed Protection (CWP). (2003). *Impacts of impervious cover on aquatic systems*, CWP, Ellicott City, Md.

Cianfrani, C. M., Hession, W. C., and Rizzo, D. M. (2006). "Watershed imperviousness impacts on stream channel condition in southeastern Pennsylvania." *J. Am. Water Resour. Assoc.*, 42(4), 941–956.

Coleman, D., MacRae, C., and Stein, E. (2005). "Effects of increases in peak flows and imperviousness on the morphology of southern California streams." Southern California Coastal Water Research Project, Costa Mesa, Calif.

Coles, J., Cuffney, T., McMahon, G., and Beaulieu, K. (2004). *The effects of urbanization on the biological, physical and chemical characteristics of coastal New England streams*, U.S. Geological Survey, Denver.

Comeleo, R. L., et al. (1996). "Relationships between watershed stressors and sediment contamination in Chesapeake Bay estuaries." *Landscape Ecol.*, 11(5), 307–319.

Cuffney, T. F., Zappia, H., Giddings, E. M. P., and Coles, J. F. (2005). "Effects of urbanization on benthic macroinvertebrate assemblages in contrasting environmental settings: Boston, Massachusetts, Birmingham, Alabama, and Salt Lake City, Utah." *Proc., Symp. 47: Effects of Urbanization on Stream Ecosystems*, 361–407.

Deacon, J., Soule, S., and Smith, T. (2005). *Effects of urbanization on stream quality at selected sites in the seacoast region in New Hampshire, 2001–2003*, U.S. Geological Survey, Denver.

Elvidge, C. D., et al. (2004). "U. S. constructed area approaches the size of Ohio." *EOS (Wash. D.C.)*, 85(24), 233–240.

Exum, L. R., Bird, S. L., Harrison, J., and Perkins, C. A. (2006). "Estimating and projecting impervious cover in the southeastern United States." U.S. Environmental Protection Agency, Athens, Ga.

Fitzpatrick, F. A., Diebel, M. W., Harris, M. A., Arnold, T. L., Lutz, M. A., and Richards, K. D. (2005). "Effect of urbanization on the geomorphology, habitat, hydrology, and fish index of biological integrity of streams in the Chicago area, Illinois, and Wisconsin." *Proc., Symp. 47: Effects of Urbanization on Stream Ecosystems*, 87–115.

Goetz, S., Wright, R., Smith, A., Zinecker, E., and Schaub, E. (2003). "IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region." *Remote Sens. Environ.*, 88, 195–208.

Hale, S. S., Paul, J. F., and Heltshe, J. F. (2004). "Watershed landscape indicators of estuarine benthic condition." *Estuaries*, 27(2), 283–295.

Holland, F., et al. (2004). "Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds." *J. Exp. Mar. Biol. Ecol.*, 298(2), 151–178.

Jantz, P., Goetz, S., and Jantz, C. (2005). "Urbanization and the loss of resource lands in the Chesapeake Bay watershed." *Environ. Manage. (N.Y.)*, 36(6), 808–825.

King, R. S., et al. (2005). "Spatial considerations for linking watershed land cover to ecological indicators in streams." *Ecol. Appl.*, 15(1), 137–153.

King, R. S., Beaman, J. R., Whigham, D. F., Hines, A. H., Baker, M. E., and Weller, D. E. (2004). "Watershed land use is strongly lined to PCBs in white perch in Chesapeake Bay subestuaries." *Environ. Sci. Technol.*, 38(24), 6546–6552.

Kratzer, E., et al. (2006). "Macroinvertebrate distribution in relation to land use and water chemistry in New York City drinking-water-supply watersheds." *J. North Am. Benthol. Soc.*, 25(4), 954–976.

Mallin, M. A., Parsons, D. C., Johnson, V. L., McIver, M. R., and CoVan, H. A. (2004). "Nutrient limitation and algal blooms in urbanizing tidal creeks." *J. Exp. Mar. Biol. Ecol.*, 298(2), 211–231.

McBride, M., and Booth, D. B. (2005). "Urban impacts on physical stream condition: Effects on spatial scale, connectivity, and longitudinal trends." *J. Am. Water Resour. Assoc.*, 41(3), 565–580.

Meador, M. R., Coles, J. F., and Zappia, H. (2005). "Fish assemblage responses to urban intensity gradients in contrasting metropolitan areas: Birmingham, Alabama, and Boston, Massachusetts." *Proc., Symposium 47: Effects of Urbanization on Stream Ecosystems*, 409–423.

Miltner, R. J., White, D., and Yoder, C. (2004). "The biotic integrity of streams in urban and suburbanized landscapes." *Landsc. Urban Plann.*, 69(1), 87–100.

Minnesota Stormwater Steering Committee (MSSC). (2005). *Minnesota stormwater manual*, MSSC.

Moore, A. A., and Palmer, M. A. (2005). "Invertebrate diversity in agricultural and urban headwater streams." *Ecol. Appl.*, 15(4), 1169–1177.

Morgan, R. P., and Cushman, S. F. (2005). "Urbanization effects on stream fish assemblages in Maryland, USA." *J. North Am. Benthol. Soc.*, 24(3), 643–655.

Ourso, R., and Frenzel, A. (2003). "Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska." *Hydrobiologia*, 501, 117–131.

Parikh, P., Taylor, M., Hoagland, T., Thurston, H., and Shuster, W. (2005). "Application of market mechanisms and incentives to reduce stormwater runoff: An integrated hydrologic, economic and legal approach." *Environ. Sci., and Pol.*, 8(2), 133–144.

Paul, J. F., Comeleo, R. L., and Copeland, J. (2002). "Landscape metrics and estuarine sediment contamination in the mid-Atlantic and southern New England regions." *J. Environ. Qual.*, 31, 836–845.

Pitt, R., Maestre, A., and Morquecho, R. (2004). "National stormwater quality database. Ver. 1.1." ⟨http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html⟩ (Jan. 28, 2008).

Poff, N., Bledsoe, B., and Cuhaciyan, C. (2006). "Hydrologic variation with land use across the contiguous U.S.: Geomorphic and ecological consequences for stream ecosystems." *Geomorphology*, 79(3–4), 264–285.

Potapova, M., Coles, J. F., Giddings, E. M., and Zappia, H. (2005). "A comparison of the influences of urbanization on stream benthic algal assemblages in contrasting environmental settings." *Proc., Symp. 47: Effects of Urbanization on Stream Ecosystems*, 333–359.

Riley, S., et al. (2005). "Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California streams." *Conserv. Biol.*, 19(6), 1894–1907.

Roy, A., Faust, C., Freeman, M., and Meyer, J. (2005). "Reach-scale effects of riparian forest cover on urban stream ecosystems." *Can. J. Fish. Aquat. Sci.*, 62, 2312–2329.

Roy, A., Freeman, B., and Freeman, M. (2006a). "Riparian influences on stream fish assemblage structure on urbanizing streams." *Landscape Ecol.*, 22(3), 385–402.

Roy, A., Freeman, M., Freeman, B., Wenger, S., Meyer, J., and Ensign, W. (2006b). "Importance of riparian forests in urban catchments contingent on sediment and hydrologic regimes." *Environ. Manage. (N.Y.)*, 37(4), 523–539.

Schiff, R., and Benoit, G. (2007). "Effects of impervious cover at multiple spatial scales on coastal watershed streams." *J. Am. Water Resour. Assoc.*, 43(3), 712–730.

Schoonover, J. E., and Lockaby, B. G. (2006). "Land cover on streams, nutrients and fecal coliform in the lower Piedmont of West Georgia." *J. Hydrol.*, 331(3–4), 371–382.

Schueler, T. (1994). "The importance of imperviousness." *Watershed Protection Techniques*, 1(3), 100–111.

Schueler, T. R. (2004). *An integrated framework to restore small urban watersheds*, Center for Watershed Protection, Ellicott City, Md.

Shuster, W. D., Bonta, J., Thurston, H., Warnemuende, E., and Smith, D. R. (2005). "Impacts of impervious surface on watershed hydrology: A review." *Urban Water*, 2(4), 263–275.

Short, T. M., Giddings, E. M. P., Zappia, H., and Coles, J. F. (2005). "Urbanization effects on habitat characteristics of streams in Boston, Massachusetts, Birmingham, Alabama, and Salt Lake City, Utah." *Proc., Symposium 47: Effects of Urbanization on Stream Ecosystems*, 317–332.

Slonecker, E., and Tilley, J. (2004). "An evaluation of the individual components and accuracies associated with the determination of impervious surfaces." *GIScience and Remote Sensing*, 41(2), 165–184.

Snyder, C. D., Young, J. A., Villela, R., and Lemarie, D. P. (2003). "Influences of upland and riparian land use on stream biotic integrity." *Landscape Ecol.*, 18(7), 647–664.

Sprague, L., Zueling, R., and. Dupree, J. (2006). *Effect of urban development on stream ecosystems along the front range of the Rocky Mountains, Colorado and Wyoming*, U.S. Geological Survey, Denver.

Sprague, L. A., Harned, D. A., Hall, D. W., Nowell, L. H., Bauch, N. J., and Richards, K. D. (2007). *Response of stream chemistry during base flow to gradients of urbanization in selected locations across the conterminous United States, 2002–2004*, U.S. Geological Survey, Denver.

Walsh, C., Sharpe, A., Breen, P., and Sonneman, J. (2001). "Effects of urbanization on streams of the Melbourne region, Victoria, Australia. I: Benthic macroinvertebrate communities." *Freshwater Biol.*, 46(4), 535–551.

Walsh, C., Waller, K., Gehling, J., and MacNally, R. (2007). "Riverine invertebrate assemblages are degraded more by catchment urbanization than riparian deforestation." *Freshwater Biol.*, 52(3), 574–587.

Walsh, C. J. (2004). "Protection of in-stream biota from urban impacts: Minimize catchment imperviousness or improve drainage design?" *Mar. Freshwater Res.*, 55(3), 317–326.

Walters, D. M., Leigh, D. S., Freeman, M. C., Freeman, B. J., and Pringle, C. M. (2003). "Geomorphology and fish assemblages in a Piedmont River basin, USA." *Freshwater Biol.*, 48(11), 1950–1970.

Wang, L., Lyons, J., Rasmussen, P., Simons, P., Wiley, T., and Stewart, P. (2003). "Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and forest ecoregion." *Can. J. Fish. Aquat. Sci.*, 60(5), 491–505.

Xian, G., Crane, M., and Su, J. (2007). "An analysis of urban development and its environmental impact on the Tampa Bay watershed." *J. Environ. Manage.*, 85(4), 965–976.