HOMER ADVISORY PLANNING COMMISSION
491 E PIONEER AVENUE
HOMER, ALASKA

NOVEMBER 5, 2014
5:30 WEDNESDAY
COWLES COUNCIL CHAMBERS

WORK SESSION AGENDA

1. Call to Order 5:30 p.m.

2. Planning Commission work list for 2015 **pg. 1**

3. Discussion of Items on the Regular Meeting Agenda

4. Public Comments
   The public may speak to the Planning Commission regarding matters on the work session agenda that are not scheduled for public hearing or plat consideration. (3 minute time limit).

5. Commission Comments

6. Adjournment

HAPC Draft 2015 Work list – 11/5/14

1. **Stormwater** – performance standards, what storm even to plan for, design criteria manual for road construction. What did Soldotna do near river? Rick to research based on CC work session.

2. **Subdivision/Roads standards -** major review of subdivision rules with attention to green infrastructure, road construction and drainage standards.

3. Chapter 4 Comp Plan review - Rick

4. Transportation Plan/HNMTTP/1986 Master Streets and Roads Plan update ??

??

<u>Upcoming Issues, will be brought forward by staff:</u>

- Towers – CC work session in October. Result: Use middle ground approach: no inspections, but safety and spatial characteristics. View shed is a concern but may not be something we can regulate…
- FEMA map update – staff will bring this forward when its ready.
- Subdivision ord – the housekeeping version! Need update title 22 with new processes for HAPC required by KPB code changes. This is not a major redo; its about public notice requirements, etc.
- Transportation Advisory Committee duties (this is generally small, that's why the committee is disbanded. The road standards/subdivision/design criteria manual are the real meat and potatoes here, see #2 above).

<u>Speakers</u>

- Invite KPB platting to talk about new subd ordinance, changes, and how HAPC is now part of the process.
- Telecommunications or tower speaker?
- Carey/public safety committee on new public safety building
- Others?

REGULAR MEETING AGENDA

1. Call to Order

2. Approval of Agenda

3. Public Comment

The public may speak to the Planning Commission regarding matters on the agenda that are not scheduled for public hearing or plat consideration. (3 minute time limit).

4. Reconsideration

5. Adoption of Consent Agenda

All items on the consent agenda are considered routine and non-controversial by the Planning Commission and are approved in one motion. There will be no separate discussion of these items unless requested by a Planning Commissioner or someone from the public, in which case the item will be moved to the regular agenda and considered in normal sequence.

A. Approval of Minutes of October 15, 2014 meeting **pg. 5**

6. Presentations

7. Reports

A. Staff Report PL 14-91, City Planner's Report **pg. 11**

8. Public Hearings

Testimony limited to 3 minutes per speaker. The Commission conducts Public Hearings by hearing a staff report, presentation by the applicant, hearing public testimony and then acting on the Public Hearing items. The Commission may question the public. Once the public hearing is closed the Commission cannot hear additional comments on the topic. The applicant is not held to the 3 minute time limit.

A. Staff Report PL 14-92, Proposed Conditional Fence Permit for a 70 ft. long, 7 ft. tall fence along Mullikin Street at 3945 Mullikin Street **pg. 13**

B. Memorandum PL 14-03, Continued public hearing for an ordinance of the Homer City Council amending Homer City Code 21.40.070, requirements, regarding standards for impervious coverage in the Bridge Creek Watershed Protection District **pg. 31**

C. Staff Report PL 14-93, Proposal for a public sign at Jack Gist Park **pg. 191**

9. Plat Consideration

10. Pending Business

11. New Business

12. Informational Materials

A. City Manager's Reports for the October 13 and October 27 City Council Meetings **pg. 205**

B. Kenai Peninsula Borough Plat Committee Notice of Decision Re: Homer Enterprises, Inc. Subdivision Resetarits Replat Preliminary Plat **pg. 209**

13. Comments of the Audience

Members of the audience may address the Commission on any subject. (3 minute time limit)

14. Comments of Staff

15. Comments of the Commission

16. Adjournment

Meetings will adjourn promptly at 9:30 p.m. An extension is allowed by a vote of the Commission.
Next regular meeting is scheduled for December 3, 2014. A work session will be held at 5:30 pm.

Session 14-18, a Regular Meeting of the Homer Advisory Planning Commission was called to order by Chair Stead at 6:30 p.m. on October 15, 2014 at the City Hall Cowles Council Chambers located at 491 E. Pioneer Avenue, Homer, Alaska.

PRESENT: COMMISSIONERS BRADLEY, HIGHLAND, STEAD, STROOZAS, VENUTI

ABSENT: BOS, ERICKSON

STAFF: CITY PLANNER ABBOUD
DEPUTY CITY CLERK JACOBSEN

Approval of Agenda

Chair Stead called for a motion to approve the agenda.

VENUTI/STROOZAS SO MOVED

There was no discussion.

VOTE: NON OBJECTION: UNANIMOUS CONSENT

Motion carried.

Public Comment

The public may speak to the Planning Commission regarding matters on the agenda that are not scheduled for public hearing or plat consideration. (3 minute time limit).

Wesley Head, city resident and owner of Beluga Air, commented to the commission regarding his sign issue. He has a sign that is on state airport land that is not in compliance with current code; however it has been there more than three decades. It was legal when it was built, has been a continuing operation, and the court cases he has reviewed it's up to the City to prove that he doesn't qualify for grandfather. He spoke to the City Planner and found that his industry is under special scrutiny for signs, which he found disturbing. He raised question of what industry his business falls into. To find that one industry is a focus for sign enforcement he feels in unethical. Lastly he expressed his concern with the handling of his notification of the appeal process and the inconsistency of personnel's judgment of what adheres in the process and what doesn't. He asked that they drop this matter, or prove that his sign doesn't qualify for grandfather after three decades, and that they explain what industry he is in.

Reconsideration

Adoption of Consent Agenda

All items on the consent agenda are considered routine and non-controversial by the Planning Commission and are approved in one motion. There will be no separate discussion of these items unless requested by a Planning Commissioner or someone from the public, in which case the item will be moved to the regular agenda and considered in normal sequence.

A. Approval of Minutes of September 17, 2014 meeting

B. A Memo from the City Clerk and a resolution of the City Council of Homer, Alaska, establishing the 2015 regular meeting schedule for the city council, economic development advisory commission, library advisory board, parks and recreation advisory commission, advisory planning commission, port and harbor advisory commission, permanent fund committee, and public arts committee.

Chair Stead called for a motion to adopt the consent agenda.

HIGHLAND/VENUTI SO MOVED.

There was no discussion

VOTE: NON OBJECTION: UNANIMOUS CONSENT.

Motion carried.

Presentations

Reports

A. Staff Report PL 14-84, City Planner's Report

City Planner Abboud reviewed the staff report.

There was brief discussion about the safe routes to school grant and the erosion around Woodard Creek.

Commissioner Highland requested a break to read the laydown materials that were provided to the Commission. Chair Stead called for a recess at 6:50 and the meeting reconvened at 6:57.

Public Hearings

Testimony limited to 3 minutes per speaker. The Commission conducts Public Hearings by hearing a staff report, presentation by the applicant, hearing public testimony and then acting on the Public Hearing items. The Commission may question the public. Once the public hearing is closed the Commission cannot hear additional comments on the topic. The applicant is not held to the 3 minute time limit.

A. Staff Report PL 14-90, An ordinance of the Homer City Council amending Homer City Code 21.40.070, requirements, regarding standards for impervious coverage in the bridge creek watershed protection district.

City Planner Abboud reviewed the staff report.

Chair Stead opened the public hearing.

Chris Story, city resident and local realtor, thanked the group for their work on the draft ordinance. He said he presented this information to the Kachemak Board of Realtors membership and those present at the meeting were in agreement that this is a positive and proactive step toward making these properties more useable, desirable, and marketable. He added that if it goes beyond this public hearing that they not only think in terms of impervious coverage versus not impervious, but also in terms of characteristics of people's homes. It's much more than a scientific calculation. He, and those has talked to, appreciate the concern that this is our one source of drinking water, but there have been no major impacts since this ordinance was written, or even before.

Bob Shavelson, Executive Director of Cook Inletkeeper, acknowledged individual property owners rights, but he is he here to talk about the rights of the public and encouraged erring on the side of caution. Treatment is always a lot more expensive than prevention, and prevention is a lot easier. In response to comment there is no evidence this is working, he submitted that there have been no violations of the Safe Drinking Water Act since this ordinance has been in place. We don't have a lot of information in place right now and are making decisions based on some speculation that there has been diminishing property values and restriction. We don't understand what the hydrology is and the impacts of the concentration of these parcels in Kelly Ranch Estates if they are developed to the levels outlined in code. There are additional factors that haven't been touched on like yard fertilizers and so forth. He encouraged them to look at this more carefully; they are making decisions without enough information and once the decisions are made, we can't go back on them.

Commissioner Venuti asked if Mr. Shavelson if he could provide data of tracking drainages into the reservoir that he mentioned at a previous meeting. Mr. Shavelson said he would.

Commissioner Stroozas questioned if the proposal relaxing regulations on four out of 2100 acres seems like a minimal figure. Mr. Shavelson reiterated that it isn't the overall number they are looking at; it's the concentration of the lots in one area.

Chair Stead queried whether or not they should close the public hearing.

There was discussion of the lack of property owners providing comment. It was suggested it may indicate they feel this is going in the right direction. It was also noted that in the laydowns, two supported the amendment, one strongly opposing it with good points why it shouldn't change.

Commissioner Highland is interested in how to get a better idea of the impact of concentrated development in the area being considered tonight. She agrees they need hydrological information and would like to know who they could contact.

HIGHLAND/VENUTI MOVED TO CONTINUE THE PUBLIC HEARING TO THE NEXT MEETING.

There was no discussion.

VOTE: NON OBJECTION: UNANIMOUS CONSENT

Motion carried.

The Commissioners discussed laydown information titled "Public Health Effects of Inadequately Managed Stormwater Runoff". Comments included:

- The report repeatedly mentions urban areas, and it isn't an urban area up there.

- It addresses waterborne illnesses linked to pathogens and it's zero in low density population areas, and the Bridge Creek watershed area is a low density populated area.
- The statement in the report that the construction of low density developments disturbs soil over larger land area, accelerating transport of sediment and associated pollutants into water bodies, may apply in this area.
- There may be a discrepancy regarding turbidity values. When turbidity goes up there are issues with bacteria coming in, but the report data shows low turbidity and problems with bacteria. It wasn't clear how they got from one place to the other.
- In best management practices, there are problems with designs for collecting runoff.
- It suggests increasing density of the people living in the area to create larger buffers to lower turbidity.

The concern of dealing with fertilizers in the area was raised, along with invasive grasses in the area. City Planner Abboud talked about challenges of being able to reasonably enforce a regulation on fertilizers and such. It was countered that adding prohibiting fertilizers and herbicides in the ordinance will at least educate people and there will be those who will comply and curb some of the uses. Regarding invasive grasses, in the section regarding reseeding, it was suggested to include wording that it be seeded with natural or native grass.

Relating back to the study, Chair Stead expressed he doesn't think there isn't much there. The biggest things they can do are limit runoff and provide natural buffers. Kelly Ranch Estates flows down to Bridge Creek.

B. Staff Report PL 14-88, An ordinance of the Homer City Council amending Homer City Code 21.70.010, Zoning permit required, and 21.90.030, Invalid land use permits, regarding the requirement for a zoning permit and the relationship of zoning violations to permit issuance

City Planner Abboud reviewed the staff report.

Chair Stead opened the public hearing. There were no public comments and the hearing was closed.

VENUTI/STROOZAS MOVED TO APPROVE THE DRAFT ORDINANCE AMENDING HCC 21.7.010 ZONING PERMITS REQUIRED AND 21.90.030 INVALID LAND USE PERMITS, REGARDING THE REQUIREMENT FOR A ZONING PERMIT AND THE RELATIONSHIP OF ZONING VIOLATIONS TO PERMIT ISSUANCE, AND FORWARD IT TO THE CITY COUNCIL FOR PUBLIC HEARING AND ADOPTION.

There was discussion that this seems to be pretty straight forward and that staff doesn't know if there will be any retroactive issues. There may be some discussion about it at the joint worksession with Council.

VOTE: NON OBJECTION: UNANIMOUS CONSENT.

Motion carried.

Plat Consideration

Pending Business

New Business

Informational Materials

A. City Manager's Report for September 22, 2014 City Council Meeting
B. Kenai Peninsula Borough Platt Committee Notice of Decisions:
   - Lakeside Village Subdivision 2014 Replat Preliminary Plat
   - Scenic View Tract A 2014 Replat Preliminary Plat
   - Forest Glen Subdivision Unit 2 2014 Replat Preliminary Plat
   - Vineyard Estates 2014 Addition Preliminary Plat
C. Beluga Air letter stamp dated 9/18/14 regarding off-premise sign
D. Planning Staff Response to Beluga Air letter dated 9/18/14
E. Army Corps of Engineers Kenai Field Office Public Notice of Application for Permit to "discharge 2040 cubic yards (cy) of pit run gravel and 49 cy of concrete for the construction of a driveway, parking lot, composting facility, and drainage ditch in Waters of the U.S." at Tract O-1 Tietjen Subdivision
F. Park, Art, Recreation, Culture (PARC) Needs Assessment Flyer

The Commission discussed the Beluga Air information item. City Planner Abboud explained that there is a requirement in the sign code for signs to come into compliance within a specified time. The dated time for Beluga Air has passed. He reviewed the process that he used in reviewing this and what has been used in other cases. Commissioner Venuti read the applicable section of code. It was requested that a response be sent to Mr. Head to let him know the Commission talked about his issue. They addressed some options relating to seasonal signage.

They also addressed the agenda for the upcoming worksession with City Council.

Comments of the Audience

Members of the audience may address the Commission on any subject. (3 minute time limit)

None

Comments of Staff

None

Comments of the Commission

Commissioners Highland, Bradley, and Venuti had no comments.

Commissioner Stroozas asked why they didn't hold a worksession. Mr. Abboud advised that the speaker canceled and he didn't know that they had an hour's worth of information to discuss.

Chair Stead encouraged the Commissioners to attend the joint worksession with Council. He said he would like to set some Commission goals at their next worksession. He also commented that as Chair he tends to let people run a little too far. He thinks the discussion is good but we need to keep moving the process forward.

Adjourn

There being no further business to come before the Commission, the meeting adjourned at 8:25 p.m. The next regular meeting is scheduled for November 5, 2014 at 6:30 p.m. in the City Hall Cowles Council Chambers.

____
MELISSA JACOBSEN, CMC, DEPUTY CITY CLERK

Approved: ________________________________

City of Homer
www.cityofhomer-ak.gov

Planning
491 East Pioneer Avenue
Homer, Alaska 99603
Planning@ci.homer.ak.us
(p) 907-235-3106
(f) 907-235-3118

STAFF REPORT PL 14-91

TO: Homer Advisory Planning Commission
FROM: Julie Engebretsen, Deputy City Planner
MEETING: November 5, 2014
SUBJECT: City Planner's Report

Park, Art, Recreation and Culture (PARC) Needs Assessment
Julie has been working hard on the needs assessment. Over 485 surveys have been completed. There is a community meeting scheduled for November 13th at Islands and Ocean, where the preliminary results of the community survey will be discussed. An update for the City Council is scheduled for the November 24th meeting.

Safe Routes to School Grant: Planning staff applied for a grant to help pay for a SRTS Plan. We expect to hear the results of the application by the end of the year.

Staff: Rick is on vacation until November 12th, Dotti is back in the office. Dotti has helped organize the Alaska Planning conference which takes place later in the month in Anchorage. She will be there assisting and attending classes when she can. Travis will also attend 2 full days of classes. Tom Stroozas, Savanna Bradley and Franco Venuti will attend the commissioner training session at the conference.

City Council meeting of 10.27.14

Resolution 14-110, A Resolution of the City Council of Homer, Alaska, Designating the Homer Education and Recreation Complex (HERC) Site as the Location for the Proposed New Homer Public Safety Building.

ADOPTED with discussion. Staff will schedule a presentation about the project when it has moved a little further along. The next Public Safety Building meeting is November 10th, and it's possible some new information about this site will be forthcoming.

Ordinance 14-49, Heliports/Helipads:
AMENDED and ADOPTED with discussion. Council decided to remove from the ordinance Heliports and Helipads as conditional uses in the General Commercial 2 District.

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STAFF REPORT PL 14-92

TO: Homer Advisory Planning Commission
THROUGH: Julie Engebretsen, Deputy City Planner
FROM: Dotti Harness-Foster, Planning Technician
DATE: November 5, 2014
SUBJECT: Conditional Fence Permit request for 3945 Mullikin Street

SYNOPSIS: The applicants propose to install a 5-7' foot high fence along Mullikan Street. A Conditional Fence Permit is needed when a fence is greater than four (4) feet in height within 20 feet of the front lot line. This is a quasi-judicial action.

Requested Action: Conduct a public hearing, and approve a Conditional Fence Permit.

Applicants:	Alan Parks, 321 Fairview Avenue, Homer AK 99603 Alison O'Hara, PO Box 2319, Homer AK 99603
Location:	3945 Mullikin Avenue, Homer, AK 99603
Legal:	DAYBREEZE PARK LOT 1 BLK 1
Parcel ID:	17510308
Lot Size:	0.24 acres
Fence height:	5 ft to 7 ft.
Fence length:	70 ft along Mullikin Street
Zoning:	Urban Residential
Land Use:	Residential
Surrounding Land Use:	North: Residential South: Residential/vacant East: Residential West: Residential
Public Notice:	Notice was mailed to 43 property owners of 45 parcels.
Comprehensive Plan:	"Appreciation of Homer's spectacular natural setting, its great views, interesting topography, as well as a tradition of concern about the quality of natural resources and the environment." Page 3-1. "Establish development standards for higher density residential development, landscaping, lighting, grading, view shed protection." Ch. 4 Implementation.

HCC 21.50.120 Fences – Conditional fence Permit: b. Prior to granting such a permit, the applicant must demonstrate and the Planning Commission must find that:

1. The issuance of such a permit is reasonably necessary, by reason of unusual or special circumstances or conditions relating to the property, for the preservation of valuable property rights for full use and enjoyment of the property;

Applicant: The purpose of the fence is to provide privacy with the establishment of a sitting area in the yard.

Analysis: Based on the Kenai Peninsula Borough's website, the lot's elevation change is approximately 12 feet, sloping downward from Soundview Avenue to the south lot line, resulting in an 8% slope. A sloping lot is not unusual in Homer, nor are there special circumstances or conditions relating to the property. Mullikin Street is four blocks long and not a high traffic street. A pedestrian walking along Mullikin Street will be able see (over the fence) the two-story residence, but not the barbeque area.

Looking northwest to the south side of the house and barbeque area. 10/22/2014.

Finding: A 70 ft long fence, 5-7 feet high along Mullikin Street would provide additional privacy allowing for the full use and enjoyment of the property.

2. The fence will not create a safety hazard for pedestrians or vehicular traffic;

Applicant: The fence is out of the sight distance triangle and is two-feet from the sidewalk.

Analysis: The proposed fence will be setback approximately 6 inches from the property line, which is approximately 2 feet from pedestrian trail, and about three feet from the edge of the asphalt. The photos on page 3 show a line strung between wooden stakes to illustrate the future location of the proposed fence. The City's Public Work Department has indicated that this leaves sufficient room for trail maintenance.

Top photo: Southbound on Mullikin Street.
Stake in foreground. 10/28/14.

Lower photo: Northbound on Millikin Street. Stakes to the left of the pedestrian path. 10/28/14.

Finding: The fence does not pose a hazard to pedestrians or vehicular traffic when properly maintained.

3. The fence is a planned architectural feature designed to avoid dominating the site or overwhelming adjacent properties and structures;

Applicant: The fence design provides privacy while being inviting and does not dominate the site or overwhelm the adjacent properties and structures.

Analysis: This corner lot is 124 feet long along Mullikin Street and 84 feet wide along Soundview Avenue. As proposed, the fence will be 70 feet along Mullikin Street, while the remaining perimeter will be unfenced. The fence height fence will vary from 5 to 7 feet with star and moon cut-outs. The fence will be constructed using 2 to 6 inch wide wooden slats.

Finding: Due to the topography and the fact that the fence borders just a portion of the lot, the fence does not dominate the site or overwhelm the adjacent properties or structures.

4. The orientation and location of the fence is in proper relation to the physical characteristics of the site and the surrounding neighborhood;

Finding: The fence will be parallel to the separated pathway. The orientation and location of the fence is in proper relation to the physical characteristics of the site and the surrounding neighborhood.

5. The fence will be of sound construction.

Applicant: (see last page of application): Fence framing is 4”x4” post with 2”x4” between posts.

Finding: The fence will be of sound construction.

c. Exception. Under no circumstances will a conditional fence permit be considered for a fence that exceeds the limits of a required sight distance triangle.

Finding: No exception to the sight distance triangle is needed.

Fire Department: No concerns.

Public Works Department: No concerns.

Staff Recommendation: Approve the request for a conditional fence permit.

ATTACHMENTS

1. Application with site plan, fence design and photos stamp dated Oct. 16, 2014
2. Public notice
3. Aerial Map

City of Homer
Planning & Zoning
491 East Pioneer Avenue
Homer, Alaska 99603-7645

Telephone (907) 235-3106
Fax (907) 235-3118
E-mail Planning@ci.homer.ak.us
Web Site www.cityofhomer-ak.gov

Conditional Fence Permit Application

Homer City Code 21.50.110(b) Fences: b. In all residential zoning districts no fence on or within 20 feet of the front lot line may exceed four feet in height.

HCC 20.50.120 allows exceptions when a Conditional Fence Permit is first approved by the Planning Commission, a $200 fee.

Applicant

Name: Alan Parks Telephone No.: 907-399-3096

Address: 321 Fairview Ave Email: alan@homerphotofest.org

Property Owner (if different than the applicant):

Name: Alison O'hara Telephone No.: 907-299-6275

Address: ______ Email: ______

PROPERTY INFORMATION:

Address: 3945 Mullikin St. Lot Size: 0.24 acres KPB Tax ID # 17510308

Legal Description of Property: Lot 1 block 1 Daybreeze park sub. T6S R13W Sec 19 S.M.

For staff use:
Date: 10/16/14 Fee submittal: Amount $200
Received by: Travis Brown Date application accepted as complete ______
Planning Commission Public Hearing Date: Nov. 5, 2014

RECEIVED
OCT 16 2014
CITY OF HOMER
PLANNING/ZONING

Where the Land Ends and the Sea Begins

HCC 21.50.120 b. Prior to granting such a permit, the applicant must demonstrate and the Planning Commission must find that:

1. The issuance of such a permit is reasonably necessary, by reason of unusual or special circumstances or conditions relating to the property, for the preservation of valuable property rights for full use and enjoyment of the property; The purpose of fence is to provide privacy with the establishment of a sitting area in yard

2. The fence will not create a safety hazard for pedestrians or vehicular traffic;
The fence is out of the sight distance triangle and is two feet from sidewalk

3. The appearance of the fence is compatible with the design and appearance of other existing buildings and structures within the neighborhood; The fence will be a natural color and compatible with design and appearance of the other exist buildings and structures within the neighborhood.

4. The fence is a planned architectural feature designed to avoid dominating the site or overwhelming adjacent properties and structures; The fence design provides privacy while being inviting and dose not dominate the site or overwhelm the adjacent properties and structures.

5. The orientation and location of the fence is in proper relation to the physical characteristics of the site and the surrounding neighborhood; yes

6. The fence will be of sound construction.

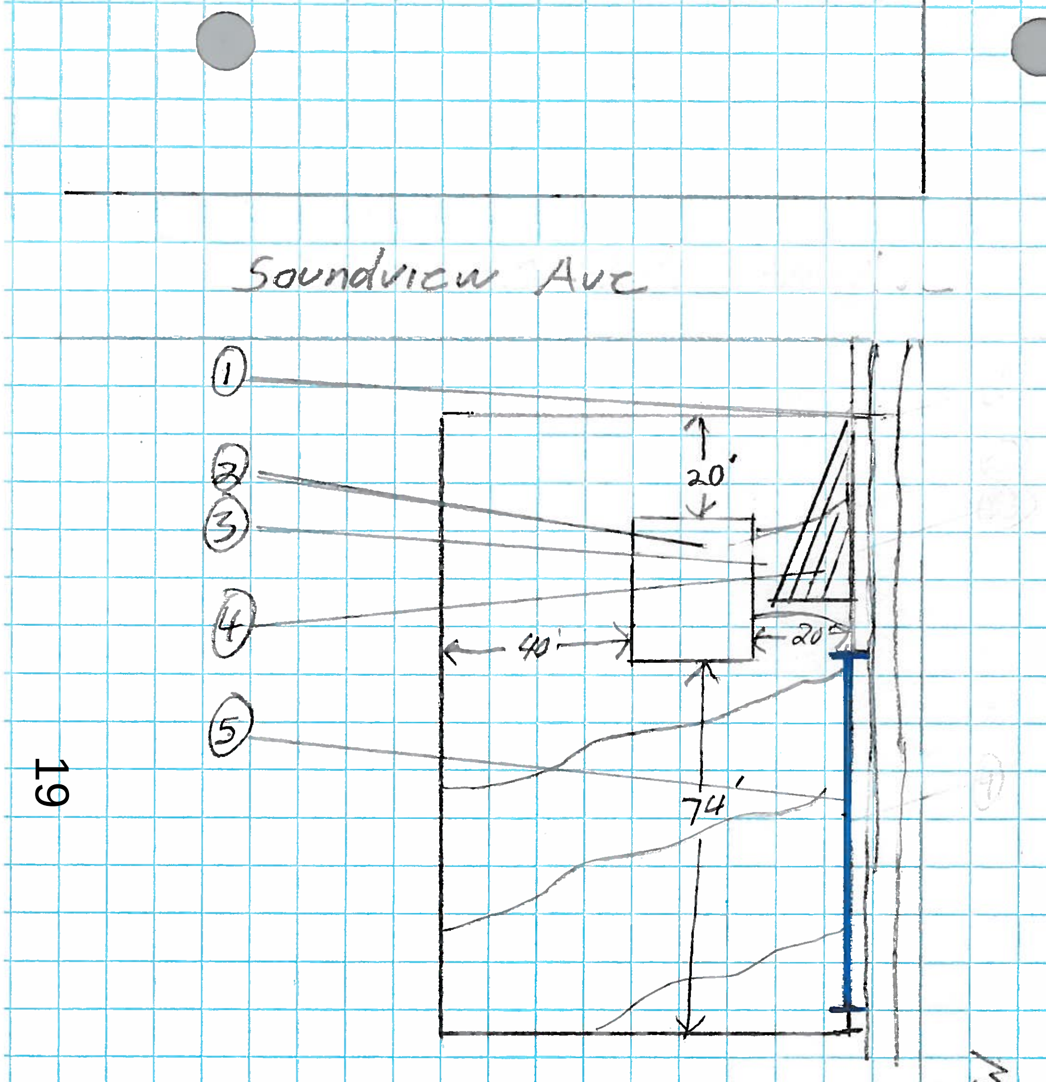
yes

c. Exception. Under no circumstances will a conditional fence permit be considered for a fence that exceeds the limits of a required sight distance triangle. (Ord. 08-29, 2008)

RECEIVED

Property Owner's signature: [signature] Date: 10.16.2014

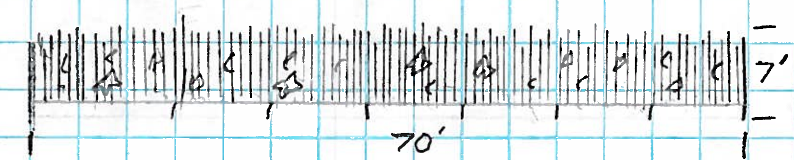
CITY OF HOMER
PLANNING/ZONING



Scale 1" = 40'

1. Sidwalk
2. Two story single family residence
3. Parking
4. Sight Distance Triangle (No-Fence)
5 Proposed Fence (See Detail

Fence Detail   Scale 1" = 20'

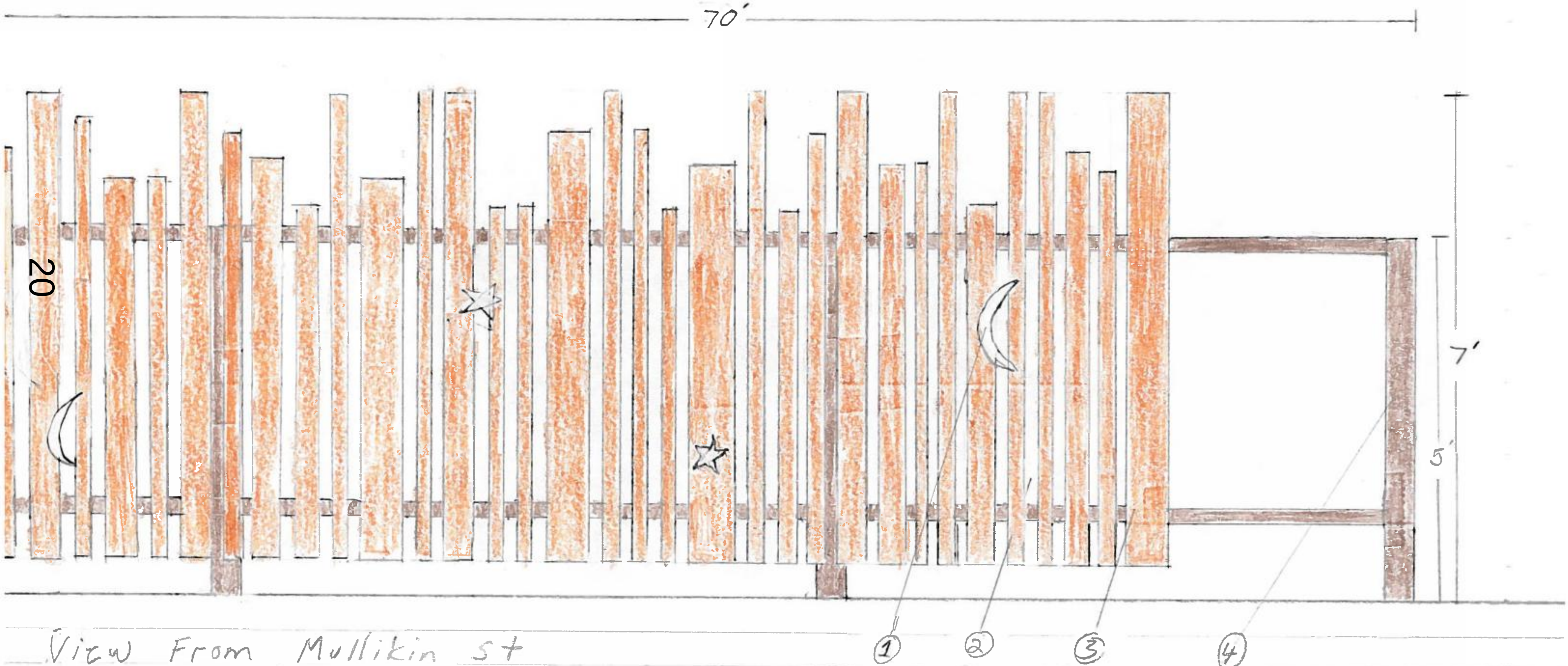


- Fence boards vary in width 2" to 6"
- Fence varies in height 5' to 7'
- Stars and Moon cut out shapes will run the lenght of fence
- Fence will be 6" in from property line

RECEIVED
OCT 16 2014
CITY OF HOMER
PLANNING/ZONING

Allison O Hara 3943 Mullikin St. Homer, AK 99603
Day Breeze Park Lot 1 Blk 1

1. Moon and Star cutouts may vary in size and location and will run the full length of fence.
2. Actual space between fence boards will be ½ inch
3. Fence boards vary in size from 1"x6 to 1"x2"
4. Fence framing is 4"x4" post with 2"x4" between post



View From Mullikin St

The Fence design provides privacy for the backyard while being inviting and a attractive addition to the neighborhood

NOTE: This fence rendering is ment to give the viewer a actuate depiction of the proposed fence the color is natural and may vary

PUBLIC HEARING NOTICE

Public notice is hereby given that the City of Homer will hold a public hearing by the Homer Advisory Planning Commission on Wednesday, November 05, 2014 at 6:30 p.m. at Homer City Hall, 491 East Pioneer Avenue, Homer, Alaska, on the following matter:

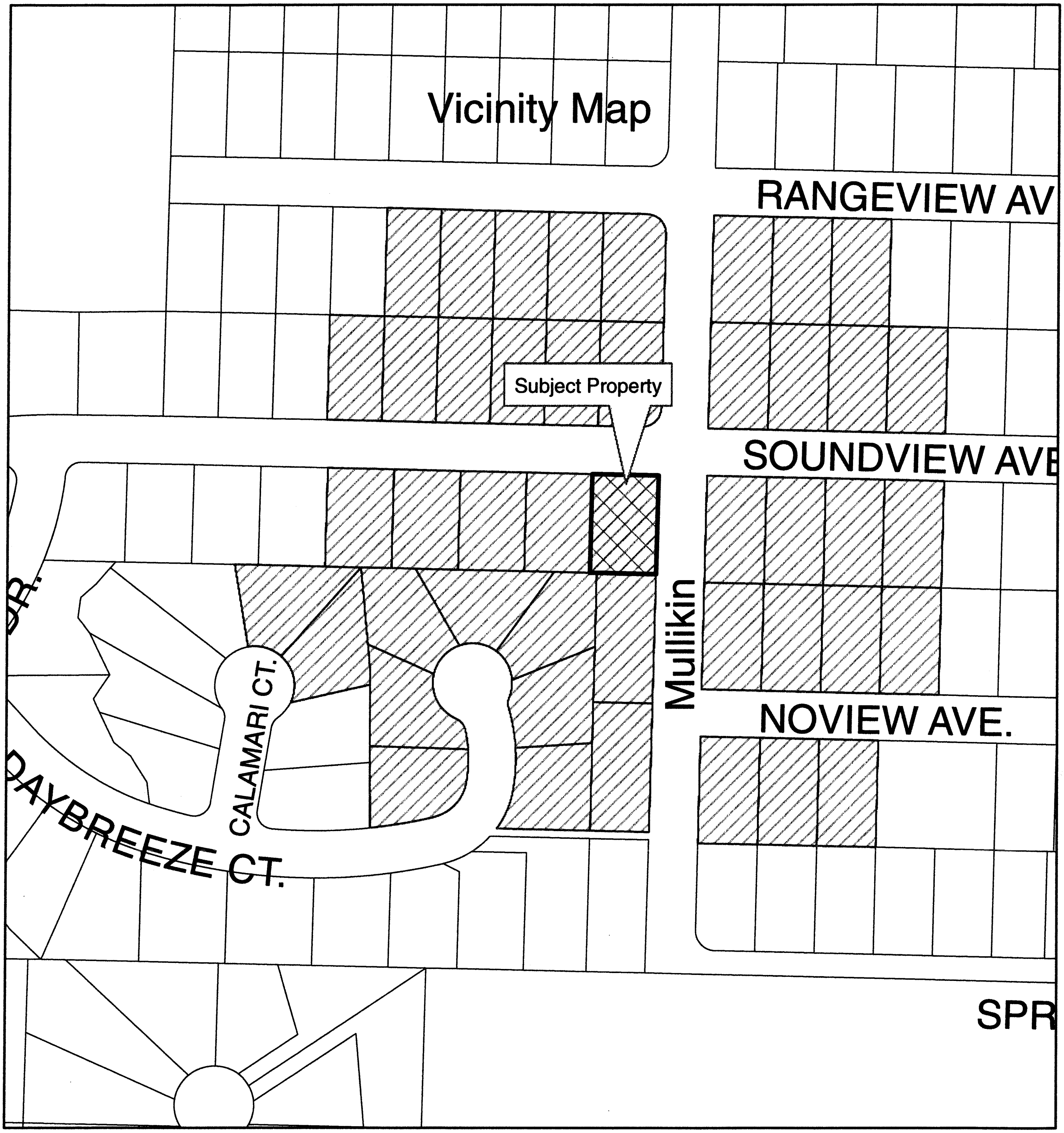
Conditional Fence Permit request to exceed the four foot height limitation within 20 feet of the front lot line pursuant to HCC 21.50.120. The proposed 7 foot tall, 70 foot long privacy fence will run along Mullikin Street at 3945 Mullikin Street, Lot 1 Block 1 Daybreeze Park T 6S R 13W SEC 19 S.M.

Anyone wishing to present testimony concerning this matter may do so at the meeting or by submitting a written statement to the Homer Advisory Planning Commission, 491 East Pioneer Avenue, Homer, Alaska 99603, by 4:00 p.m. on the day of the meeting.

The complete proposal is available for review at the City of Homer Planning and Zoning Office located at Homer City Hall. For additional information, please contact Travis Brown at the Planning and Zoning Office, 235-3106.

NOTICE TO BE SENT TO PROPERTY OWNERS WITHIN 300 FEET OF PROPERTY.

VICINITY MAP ON REVERSE



City of Homer
Planning and Zoning Department
October 22, 2014

Request for a conditional fence permit

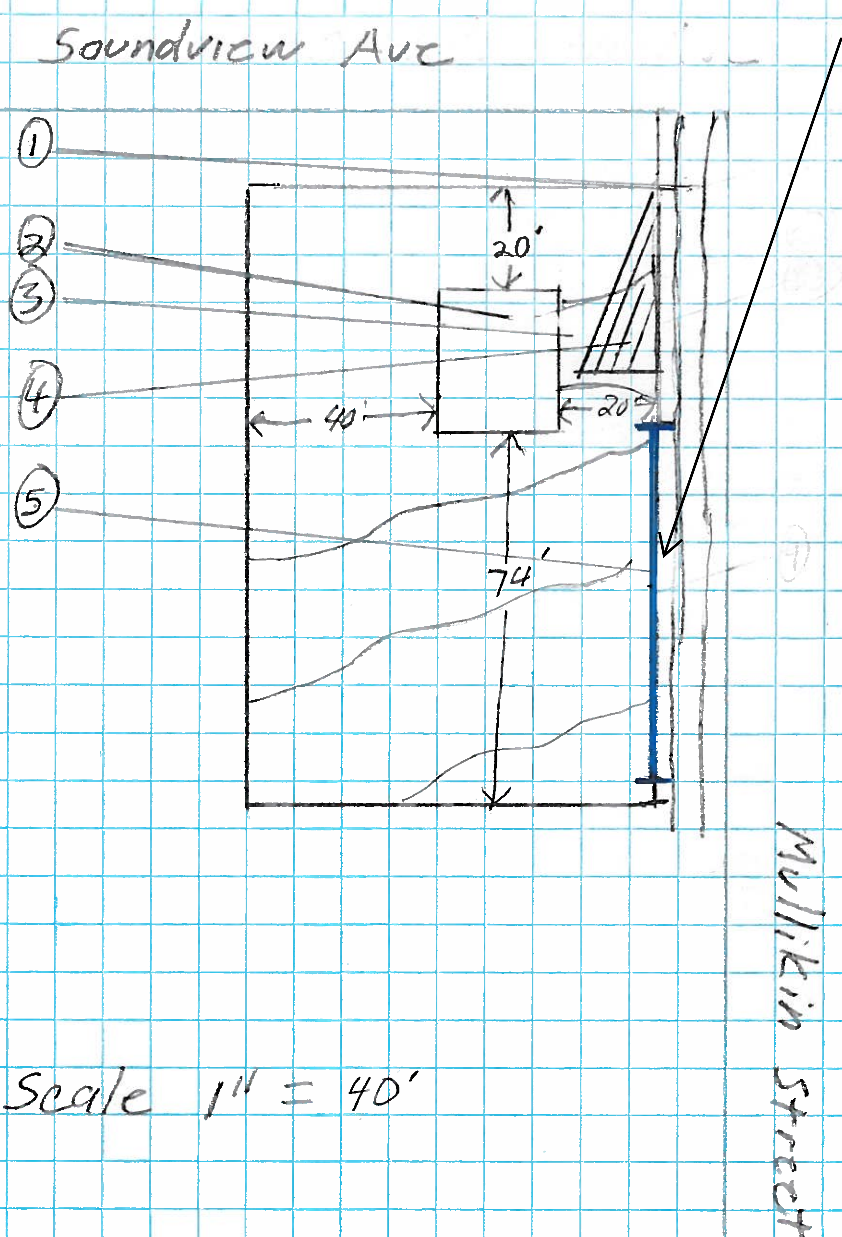
Parcels within 300 feet are marked and property owners notified.

Feet
0 150 300

N

Disclaimer:
It is expressly understood the City of Homer, its council, board, departments, employees and agents are not responsible for any errors or omissions contained herein, or deductions, interpretations or conclusions drawn therefrom.

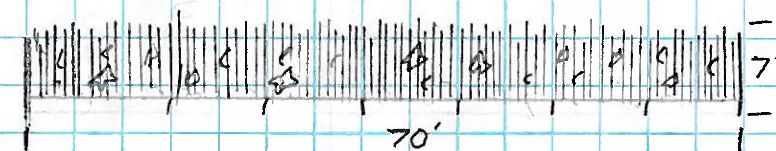
Proposed Fence Location



1. sidwalk
2. Two story single family residence
3. Parking
4. Sight Distance Triangle (No-Fence)
5 Proposed Fence (See Detail

Scale 1" = 40'

Fence Detail Scale 1" = 20'



- Fence boards vary in width 2" to 6"
- Fence varies in height 5' to 7'
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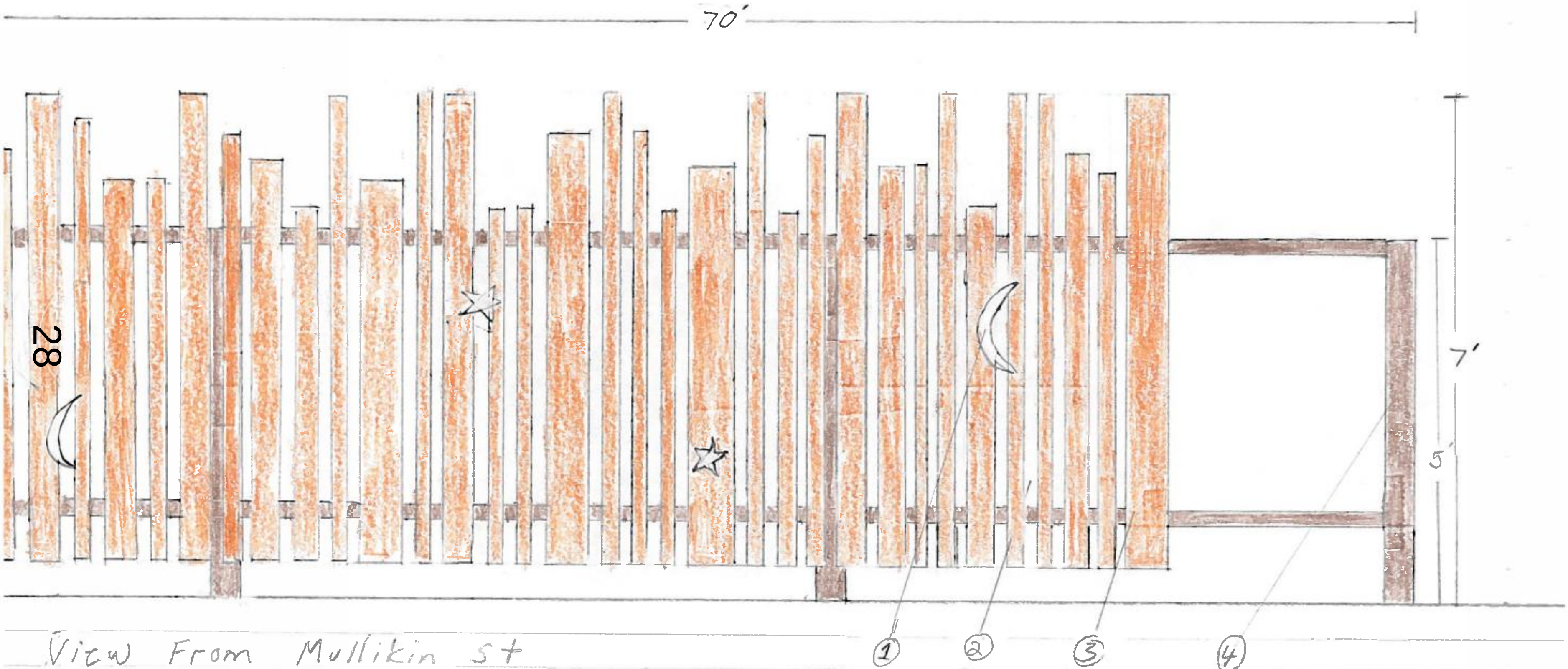
RECEIVED
OCT 16 2014
CITY OF HOMER
PLANNING/ZONING

Allison O Hara 5945 Mullikin St. Homer, AK 99603
Day Breeze Park Lot 1 Blk 1

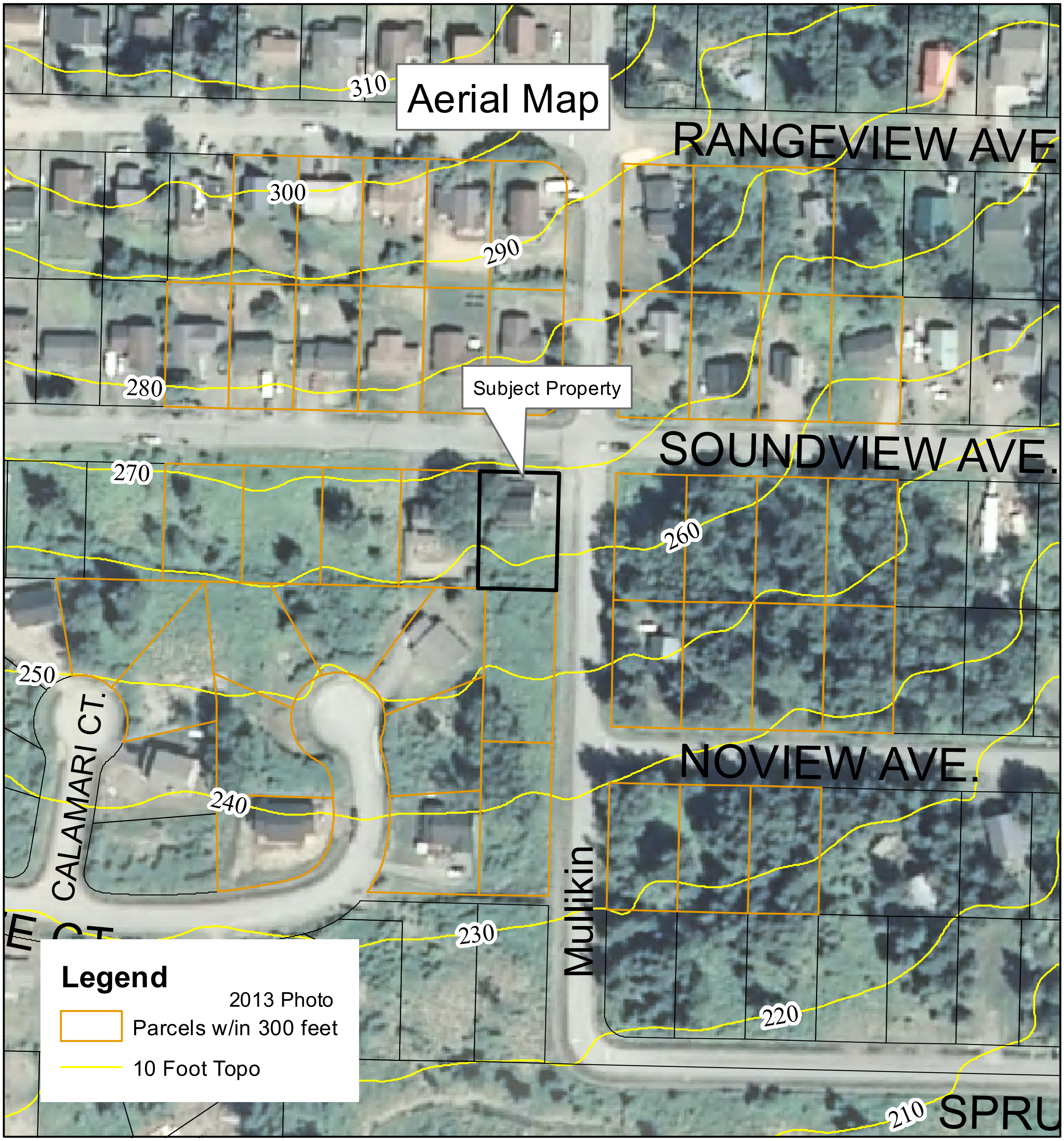
1. Moon and Star cutouts may vary in size and location and will run the full length of fence.
2. Actual space between fence boards will be ½ inch
3. Fence boards vary in size from 1" x 6 to 1" x 2"
4. Fence framing is 4" x 4" post with 2" x 4" between post



View From Mullikin St

The Fence design provides privacy for the backyard while being inviting and a attractive addition to the neighborhood

NOTE: This fence rendering is ment to give the viewer a actuate depiction of the proposed fence the color is natural and may vary



City of Homer
Planning and Zoning Department
October 30, 2014

Request for a conditional fence permit

Feet
0 130 260

N

Disclaimer:
It is expressly understood the City of Homer, its council, board, departments, employees and agents are not responsible for any errors or omissions contained herein, or deductions, interpretations or conclusions drawn therefrom.

City of Homer
www.cityofhomer-ak.gov

Planning
491 East Pioneer Avenue
Homer, Alaska 99603
Planning@ci.homer.ak.us
(p) 907-235-3106
(f) 907-235-3118

MEMORANDUM PL 14-03

TO: Homer Advisory Planning Commission

THROUGH: Julie Engebretsen, Deputy City Planner

FROM: Travis Brown, Planning Clerk

DATE: October 30, 2014

SUBJECT: Continued public hearing for an ordinance amending HCC 21.040.070, requirements, regarding standards for impervious coverage in the Bridge Creek Watershed Protection District

---

A public hearing for a proposal to amend the Bridge Creek Watershed Protection District was held on October 15, 2014. Following public testimony and discussion, the Planning Commission moved to continue the public hearing at their next meeting on November 5, 2014.

This memo provides all of the materials of the public hearing including all public comments received to-date.

Attachments:
Staff Report 14-90 with attachments, including the proposed ordinance
Minutes excerpt of October 15, 2014 public hearing
Bob Shavelson email and attachment dated October 16, 2014
Laydown comments at October 15, 2014 meeting:

- Nancy Hillstrand letter and informational item dated October 14, 2014
- Julie Woodworth letter dated October 15, 2014
- Phil Clay letter dated October 15, 2014
- Bob Shavelson letter on behalf of Cook Inlet Keeper dated October 15, 2014

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Staff Report PL 14-90

TO:	Homer Advisory Planning Commission
THROUGH:	Rick Abboud, City Planner
FROM:	Julie Engebretsen, Deputy City Planner
DATE:	October 15, 2014
SUBJECT:	Draft Ordinance 14-xx Amendments to the Bridge Creek Watershed Protection District

---

Introduction

In April, Chris Story, President of the Kachemak Board of Realtors, made a presentation on to the HAPC on some potential changes to the Bridge Creek Watershed Protection District regulations. The Planning Commission subsequently had several work sessions and heard from guest speakers Bob Shavelson of Cook InletKeeper and Todd Cook, City of Homer Water/Wastewater Superintendent.

Analysis

Staff review of the zoning code amendment per 21.95.040 is an attached memorandum.

The ordinance will make three main changes to 21.40.070. All changes apply only to lots under three acres in size.

1. Parcels less than three acres will be allowed to have up to 5,500 square feet of impervious surface.
2. Disturbed areas will be reseeded by August 31st, 40 gallons of storm water retention are required on every lot, and when determined by the City Planner, infiltration ditches next to driveways may be required. Mitigation plans will no longer be required.
3. Up to 500 square feet of uncovered deck, and one accessory structure under 200 square feet, may be constructed and not count toward the impervious surface maximum.

Total Impact of these changes to the watershed

The watershed are consists of approximately 2,100 acres, subdivided into 255 lots. Staff estimates there are 93 developable lots affected by these changes. There are more lots less than three acres, but they are not readily developable due to limiting factors such as conservation easements, lack of infrastructure, or proximity to the reservoir.

The calculations below assume all 93 property owners develop to the maximum allowed.

- Total impervious coverage allowed under the existing rules: **9.24 acres**
- Total impervious coverage under the proposed changes = **13.24 acres**

This is an increase of 4 acres from the existing rules. Private parcels can currently create 88.2 acres of imperious coverage at 4.2% of the watershed area. The proposed changes raise that potential to 92.2 acres of impervious coverage, or 4.39% of the watershed area.

Public Notice

A cover letter and public notice was mailed to all property owners within the Bridge Creek Watershed Protection District. Public notice was advertised in the local newspaper as required by code. As of the writing of this staff report, no comments had been received.

Staff Recommendation: Conduct a public hearing and forward a recommendation to the City Council

Attachments

Memorandum – staff review of the code amendment per 21.95.040
Draft Ordinance
Map dated 8/28/14
Letter to watershed land owners
Board of Realtors materials from 4/16/14 HAPC work session

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Memorandum

TO: Homer Advisory Planning Commission
THROUGH: Rick Abboud, City Planner
FROM: Julie Engebretsen, Deputy City Planner
MEETING: October 15, 2014
SUBJECT: AN ORDINANCE OF THE HOMER CITY COUNCIL AMENDING HOMER CITY CODE 21.40.070, REQUIREMENTS, REGARDING STANDARDS FOR IMPERVIOUS COVERAGE IN THE BRIDGE CREEK WATERSHED PROTECTION DISTRICT.

This memo contains the planning staff review of the zoning code amendment as required by HCC 21.95.040.

Planning Staff review of the **code amendment** per 21.95.040
The Planning Department shall evaluate each amendment to this title that is initiated in accordance with HCC 21.95.010 and qualified under HCC 21.95.030, and may recommend approval of the amendment only if it finds that the amendment:

a. Is consistent with the comprehensive plan and will further specific goals and objectives of the plan.

Staff response: The 2008 Comprehensive Plan Chapter 4 Land Use Goal 2 Objective B states: "Establish development standards and require development practices that protect environmental functions." The amendment is consistent with the plan be creating new, consistent development standards.

b. Will be reasonable to implement and enforce.

Staff response: Under current code, property owners with parcels smaller than 2.5 acres may apply to the Planning Commission for approval of a mitigation plan. This is time consuming for the applicant, staff and the Planning Commission. The mitigation plans over the past ten years have been inconsistent. It's unclear to staff if the mitigation plan process has resulted in anything other than a disincentive to develop in the watershed due to the administrative process. The amendments will simplify city code, and will be easier to implement and enforce than the current code.

c. Will promote the present and future public health, safety and welfare.

Staff response: The amendment promotes present and future public health, safety and welfare by creating clear, consistent regulation for small parcel development in the watershed.

d. Is consistent with the intent and wording of the other provisions of this title.

Staff response: This amendment is consistent with the intent, wording and purpose of HCC Title 21. The city attorney has reviewed and amended the ordinance for consistency.

CITY OF HOMER
ORDINANCE 14-xx

City Manager

AN ORDINANCE OF THE HOMER CITY COUNCIL AMENDING HOMER CITY CODE 21.40.070, REQUIREMENTS, REGARDING STANDARDS FOR IMPERVIOUS COVERAGE IN THE BRIDGE CREEK WATERSHED PROTECTION DISTRICT.

THE CITY OF HOMER ORDAINS:

Section 1. Homer City Code 21.40.070, Requirements, is amended to read as follows:

21.40.070 Requirements. The requirements of this section shall apply to all structures and uses in the BCWP district unless more stringent requirements are required pursuant to Chapter 21.71 HCC. The City of Homer water utility is exempt from this section.

a. Impervious Coverage.

1. Lots **three** ~~two and one-half~~ acres and larger shall have a maximum total impervious coverage of 4.2 percent.

2. Lots smaller than **three** ~~two and one-half~~ acres shall have a maximum total impervious coverage of **5,500 square feet** ~~4.2 percent, except as provided in subsection (a)(3) of this section~~.

3. Lots smaller than **three** ~~two and one-half~~ acres **shall comply with the following performance standards:** ~~may be allowed impervious coverage up to 6.4 percent if (a) the owner submits a lot-specific mitigation plan for Planning Commission's approval, and (b) if approved, thereafter implements and continuously complies with the approved plan. The mitigation plan must be designed to mitigate the effect of impervious coverage on water flow and the effect of loss of vegetation created by the impervious coverage~~

a. Disturbed areas shall be reseeded by August 31st

b. Storm water retention of 40 gallons must be provided on site, in the form of one or a combination of dry wells, rain barrels, rain gardens, foot drain retention or other method approved by the City Planner. The storm water retention is intended to mitigate the effect of impervious coverage and the resulting loss of vegetation on water flow.

c. When the City Planner finds that special site considerations such as topography or drainage warrant such treatment, a ditch lined with filter fabric and rock shall be constructed to slow water runoff from the driveway and encourage infiltration of water into the ground.

b. Impervious Coverage Calculations.

1. For the purpose of calculating impervious coverage on lots smaller than **three** ~~two and one-half~~ acres, **up to 500 square feet of uncovered deck attached to a**

[**Bold and underlined added**. ~~Deleted language stricken through~~.]

residence, and one accessory structure with a footprint area up to 200 square feet are excluded from the calculation ~~driveways and walkways may be partially or fully excluded from the calculation, if constructed and maintained in accordance with a mitigation plan, submitted and approved in accordance with subsection (a)(3) of this section~~.

2. Except as otherwise provided in this section, parcels of land subdivided after February 25, 2003, shall be allowed a total impervious coverage of 4.2 percent including right-of-way (ROW) dedication. ROW coverage area shall be calculated as 50 percent of the total area of the dedicated ROW. The impervious coverage allowed for the subdivided parcels shall be calculated after deducting the ROW coverage from the total parcel allowance according to the following formula:

Formula:

(Area of parcel being subdivided) x 0.042 = Total allowed impervious coverage (TAC)

(Area of ROW dedication) x 0.5 = ROW coverage (ROW C)

(TAC) – (ROW C) = Allowed impervious coverage for remainder of parcel being subdivided

(Area of parcel being subdivided) – (Area of ROW dedication) = New parcel area

(Allowed impervious coverage for remainder) ÷ (New parcel area) x 100 = Percent impervious coverage allowed on subdivided lots.

c. Additional Requirements for Subdivisions and Lots.

1. Lots created by subdivision after February 25, 2003, shall be a minimum of four and one-half acres.

2. Applications for subdivisions, dedications, and vacations of easements and rights-of-way in the BCWP district must be approved by the Planning Commission prior to submission to the Kenai Peninsula Borough.

d. Building Setbacks. Buildings must be set back from the Bridge Creek Reservoir and from streams as provided in HCC 21.40.110 and 21.40.120.

e. Sewer Systems. Appropriate to the use of the lot, each lot shall be served by a septic or sewer system approved by the Alaska State Department of Environmental Conservation (ADEC). Stream setbacks equal to 100 feet for drain fields and subsurface discharge and 250 feet for raised septic systems are required.

f. Ongoing Construction and Timber Harvesting. All activities including, but not limited to, timber harvesting, road building, subdivision and building activities involving loss of vegetation ground cover or soil disturbance and that are in process on February 25, 2003, shall be required to obtain permits under this chapter and shall fully conform to the terms of this chapter. Activities leaving disturbed or lost vegetative ground cover, disturbed soils without revegetation or leaving slash piles will be considered in process for the purposes of this subsection, regardless of when the activity occurred.

g. Pending Subdivisions. Subdivisions that have not received final plat approval by February 25, 2003, shall obtain approval from the Planning Commission and shall be required to conform to the requirements of this chapter.

[**Bold and underlined added**. ~~Deleted language stricken through~~.]

Section 2. This Ordinance is of a permanent and general character and shall be included in the City Code.

ENACTED BY THE CITY COUNCIL OF HOMER, ALASKA, this ____ day of _______________ 2014.

CITY OF HOMER

____

MARY E. WYTHE, MAYOR

ATTEST:

____

JO JOHNSON, MMC, CITY CLERK

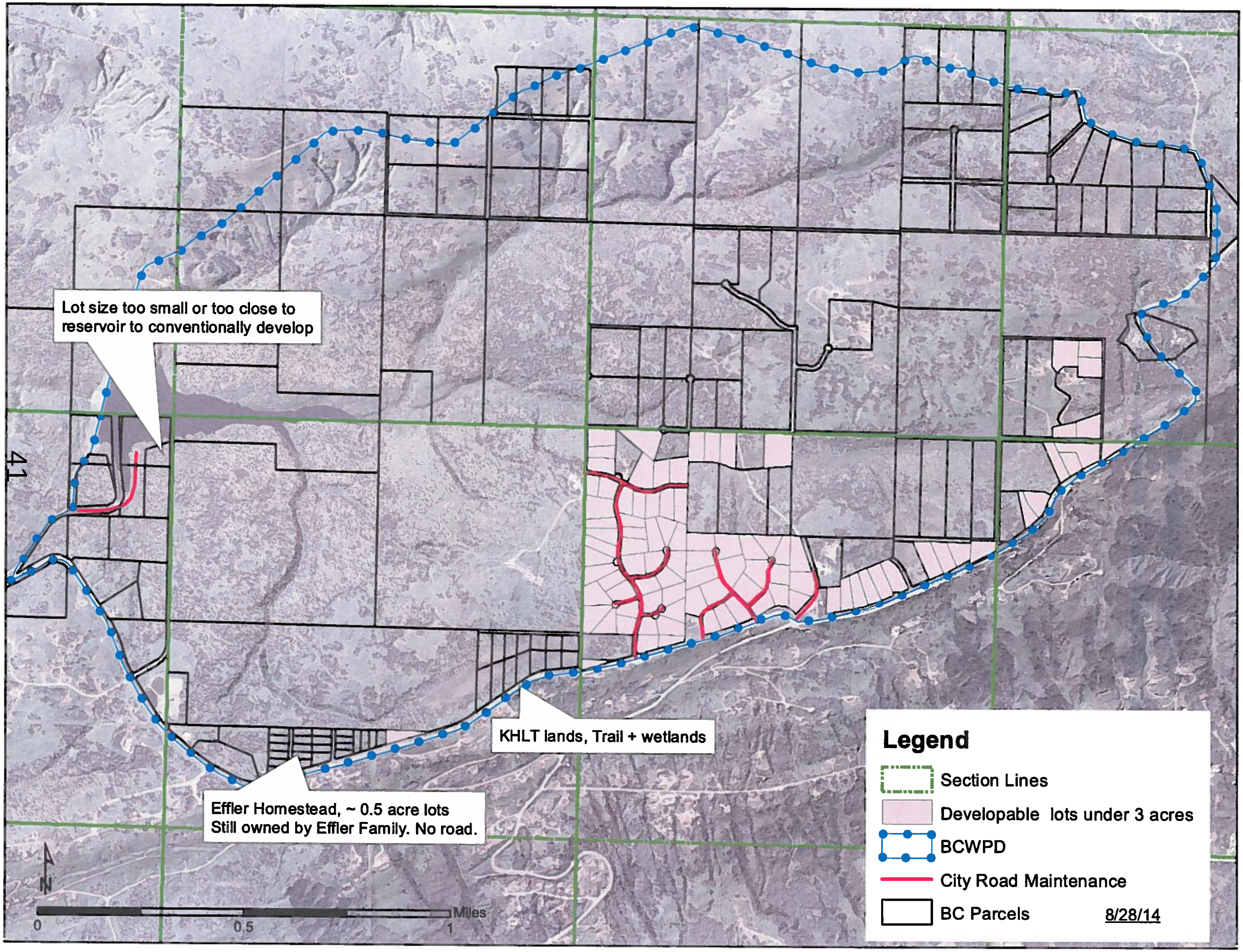
AYES:
NOES:
ABSTAIN:
ABSENT:

First Reading:
Public Hearing:
Second Reading:
Effective Date:

Reviewed and approved as to form:

________________________________	________________________________
Walt Wrede, City Manager	Thomas F. Klinkner, City Attorney
Date: __________________________	Date: __________________________

[**Bold and underlined added**. ~~Deleted language stricken through~~.]


Lot size too small or too close to reservoir to conventionally develop
KHLT lands, Trail + wetlands
Effler Homestead, ~ 0.5 acre lots
Still owned by Effler Family. No road.
Legend
Section Lines
Developable lots under 3 acres
BCWPD
City Road Maintenance
BC Parcels
8/28/14
0
0.5
1
Miles
N

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October 3, 2014

Dear Bridge Creek Watershed Property Owner;

The City of Homer Planning Commission is considering some changes to the watershed zoning rules. The Commission would like to hear from you! The proposed changes will only affect lots smaller than three acres. The rules for larger lots will remain unchanged. The goal of the changes is to make the rules easier to administer, enforce, and to ease the regulations for the smallest lots in the watershed, which are the most affected. Overall the changes would allow a small increase in impervious coverage in relation to the watershed as a whole.

The Commission will hold a public hearing on Wednesday, October 15th, at 6:30 PM, in the City Hall Cowles Council Chambers. You can testify at the meeting, or provide comments in writing by 4 pm the day of the meeting. (See reverse for more public notice information.)

For lots under three acres, there are three main changes:

- First, up to 5,500 square feet may be developed. Under the current rules, only 4.2% of the lot area may be developed, or 6.4% with a mitigation plan. This will change to a flat 5,500 square feet for all lots less than three acres.
- Second, all lots less than three acres will be required to meet some minimum requirements. This is in place of the current mitigation plan requirement.
  - a. Disturbed areas shall be reseeded by August 31st
  - b. Storm water retention of 40 gallons must be provided on site, in the form of one or a combination of dry wells, rain barrels, rain gardens, foot drain retention or other method approved by the City Planner. The storm water retention is intended to mitigate the effect of impervious coverage and the resulting loss of vegetation on water flow.
  - c. When the City Planner finds that special site considerations such as topography or drainage warrant such treatment, a ditch lined with filter fabric and rock shall be constructed to slow water runoff from the driveway and encourage infiltration of water into the ground.
- Third, for lots less than three acres, up to 500 square feet of uncovered deck attached to a residence, and one accessory structure (like a tool shed or greenhouse) with a footprint area up to 200 square feet are excluded from the calculation.

If you would like more information, please visit the Planning Department website at **http://www.cityofhomer-ak.gov/planning,** email: planning @ci.homer.ak.us, or call 235-3106.

Sincerely,

Rick Abboud
City Planner

PUBLIC HEARING NOTICE

Public notice is hereby given that the City of Homer will hold a public hearing by the Homer Advisory Planning Commission on Wednesday, October 15, 2014 at 6:30 p.m. at Homer City Hall, 491 East Pioneer Avenue, Homer, Alaska, on the following matter:

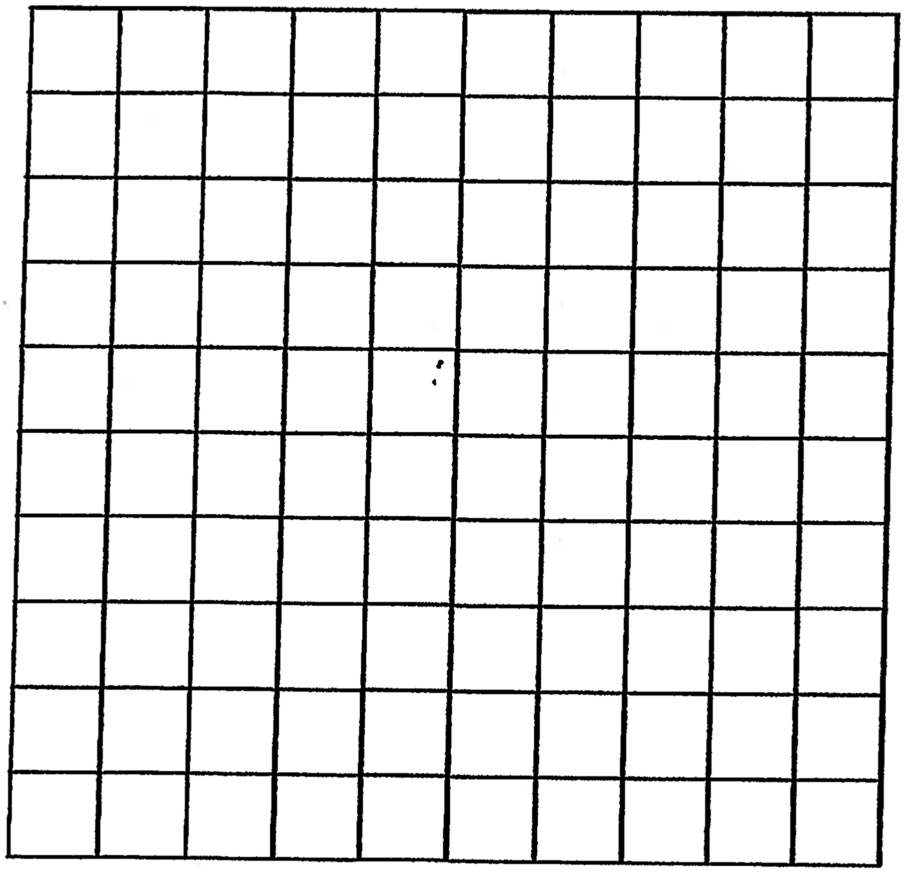
> AN ORDINANCE OF THE HOMER CITY COUNCIL AMENDING HOMER CITY CODE 21.40.070, REQUIREMENTS, REGARDING STANDARDS FOR IMPERVIOUS COVERAGE IN THE BRIDGE CREEK WATERSHED PROTECTION DISTRICT.

Anyone wishing to present testimony concerning this matter may do so at the meeting or by submitting a written statement to the Homer Advisory Planning Commission, 491 East Pioneer Avenue, Homer, Alaska 99603, by 4:00 p.m. on the day of the meeting.

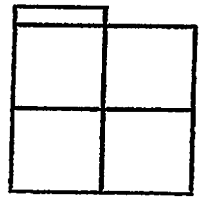
The complete proposal is available for review at the City of Homer Planning and Zoning Office located at Homer City Hall. For additional information, please contact Rick Abboud at the Planning and Zoning Office, 235-3106.

Kachemak Board of Realtors HAPC laydown 4/16/14 ws

WHAT YOU PAY FOR
and
WHAT YOU PAY TAXES ON



WHAT YOU GET TO USE

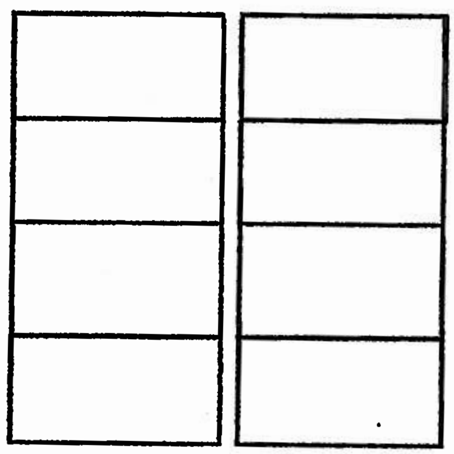


The Kachemak Board of Realtors is asking the Homer Planning Commission to reconsider the Bridge Creek Watershed Protection Ordinance. This ordinance has had a severe negative impact on the use a and marketability of the property in the area. This has been witnessed first hand in Kelly Ranch Estates. Originally these lots sold quickly and many were developed with nice middle range homes. Upon the passage of BCWP ordinance marketing has become extremely difficult. This of course is only one area of the watershed, but it is a good example of what has happened and the inhibitions on any future development in the area.

The Realtors are not insensitive to the purpose of the ordinance and would like to suggest to the commission a simpler manner of handling the watershed protection while at the same time allowing the smaller lots to develop.

The watershed is about 2100 acres. The reservoir itself is about 35 acres. This leaves 2065 acres. If you allow 4.2% of that remaining land to be developed that would be a total of 88 acres of impervious area.

There are 30 non-city owned lots comprising 1236 acres that could still be subdivided to the minimum lot size of 4.5 acres. This could generate an additional 262 lots at most. Added to the existing 150 smaller lots this is a total of 412 potential lots.



Above is 40 acres with a 60 ft ROW through acre tract with a 30 ft wide road bed you would have 30' x 1320' length = .9 acres or 2.3% of the property impermeable due to the road. If we take 2.3% of the entire 1236 acres of large lots is 28 acres that needs to be deducted for roads. So 88 acres of total impermeable minus the 28 acres for roads = 60 acres for homeowner development. Spread over 412 lots this is 6343 square feet per lot.

If you rewrite the uses to be residential with maybe secondary home business usage and limit the larger animals you make the watershed district strictly residential. Eliminate the increased impermeable allowance for an engineered discharge and simply allow 6300 square feet of impermeable development per lot. This keeps the larger parcels strictly residential, protects the watershed even if they subdivide and provides a means for the smaller lots to be utilized in a more practical manner and become more marketable.

Here's an example:

2000 sf house + 600 sf garage + 1200 shop + 12'x200' driveway = 6200 impervious sf. This allowance give great flexibility to the smaller lots and in the end allow only 88 acres of impermeable impact on the 2100 acres. It also leaves a built in cushion as the City of Homer owns 330 acres besides the reservoir itself.

So in summary:

Only same 88 acres are impacted.

Watershed is strictly residential.

No engineering for more impermeable usage.

More flexible usage for smaller parcels.

More control on larger parcels.

Summary of Larger Lots.

Size Acres	Number	Total sf	Possible 196,020 sf (4.5 acre) lots
115	1	5,009,400	25
130	1	5,662,800	28
160	1	6,969,600	34
111	1	4,835,160	24
80	2	6,969,600	34
40	6	10,454,400	52
50	1	2,178000	10
35	1	1,524,600	7
34	1	1,481,040	7
30	1	1,306,800	6
20	3	2,613,600	13
11	1	479,160	2
10	1	435,600	2
18	1	784,080	3
9	8	3,136,320	15
	30	53,840,160 (1236 ac)	262

B. A Memo from the City Clerk and a resolution of the City Council of Homer, Alaska, establishing the 2015 regular meeting schedule for the city council, economic development advisory commission, library advisory board, parks and recreation advisory commission, advisory planning commission, port and harbor advisory commission, permanent fund committee, and public arts committee.

Chair Stead called for a motion to adopt the consent agenda.

HIGHLAND/VENUTI SO MOVED.

There was no discussion

VOTE: NON OBJECTION: UNANIMOUS CONSENT.

Motion carried.

Presentations

Reports

A. Staff Report PL 14-84, City Planner's Report

City Planner Abboud reviewed the staff report.

There was brief discussion about the safe routes to school grant and the erosion around Woodard Creek.

Commissioner Highland requested a break to read the laydown materials that were provided to the Commission. Chair Stead called for a recess at 6:50 and the meeting reconvened at 6:57.

Public Hearings

Testimony limited to 3 minutes per speaker. The Commission conducts Public Hearings by hearing a staff report, presentation by the applicant, hearing public testimony and then acting on the Public Hearing items. The Commission may question the public. Once the public hearing is closed the Commission cannot hear additional comments on the topic. The applicant is not held to the 3 minute time limit.

A. Staff Report PL 14-90, An ordinance of the Homer City Council amending Homer City Code 21.40.070, requirements, regarding standards for impervious coverage in the bridge creek watershed protection district.

City Planner Abboud reviewed the staff report.

Chair Stead opened the public hearing.

Chris Story, city resident and local realtor, thanked the group for their work on the draft ordinance. He said he presented this information to the Kachemak Board of Realtors membership and those present at the meeting were in agreement that this is a positive and proactive step toward making these properties more useable, desirable, and marketable. He added that if it goes beyond this public hearing that they not only think in terms of impervious coverage versus not impervious, but also in terms of characteristics of people's homes. It's much more than a scientific calculation. He, and those has talked to, appreciate the concern that this is our one source of drinking water, but there have been no major impacts since this ordinance was written, or even before.

Bob Shavelson, Executive Director of Cook Inletkeeper, acknowledged individual property owners rights, but he is he here to talk about the rights of the public and encouraged erring on the side of caution. Treatment is always a lot more expensive than prevention, and prevention is a lot easier. In response to comment there is no evidence this is working, he submitted that there have been no violations of the Safe Drinking Water Act since this ordinance has been in place. We don't have a lot of information in place right now and are making decisions based on some speculation that there has been diminishing property values and restriction. We don't understand what the hydrology is and the impacts of the concentration of these parcels in Kelly Ranch Estates if they are developed to the levels outlined in code. There are additional factors that haven't been touched on like yard fertilizers and so forth. He encouraged them to look at this more carefully; they are making decisions without enough information and once the decisions are made, we can't go back on them.

Commissioner Venuti asked if Mr. Shavelson if he could provide data of tracking drainages into the reservoir that he mentioned at a previous meeting. Mr. Shavelson said he would.

Commissioner Stroozas questioned if the proposal relaxing regulations on four out of 2100 acres seems like a minimal figure. Mr. Shavelson reiterated that it isn't the overall number they are looking at; it's the concentration of the lots in one area.

Chair Stead queried whether or not they should close the public hearing.

There was discussion of the lack of property owners providing comment. It was suggested it may indicate they feel this is going in the right direction. It was also noted that in the laydowns, two supported the amendment, one strongly opposing it with good points why it shouldn't change.

Commissioner Highland is interested in how to get a better idea of the impact of concentrated development in the area being considered tonight. She agrees they need hydrological information and would like to know who they could contact.

HIGHLAND/VENUTI MOVED TO CONTINUE THE PUBLIC HEARING TO THE NEXT MEETING.

There was no discussion.

VOTE: NON OBJECTION: UNANIMOUS CONSENT

Motion carried.

The Commissioners discussed laydown information titled "Public Health Effects of Inadequately Managed Stormwater Runoff". Comments included:

- The report repeatedly mentions urban areas, and it isn't an urban area up there.

- It addresses waterborne illnesses linked to pathogens and it's zero in low density population areas, and the Bridge Creek watershed area is a low density populated area.
- The statement in the report that the construction of low density developments disturbs soil over larger land area, accelerating transport of sediment and associated pollutants into water bodies, may apply in this area.
- There may be a discrepancy regarding turbidity values. When turbidity goes up there are issues with bacteria coming in, but the report data shows low turbidity and problems with bacteria. It wasn't clear how they got from one place to the other.
- In best management practices, there are problems with designs for collecting runoff.
- It suggests increasing density of the people living in the area to create larger buffers to lower turbidity.

The concern of dealing with fertilizers in the area was raised, along with invasive grasses in the area. City Planner Abboud talked about challenges of being able to reasonably enforce a regulation on fertilizers and such. It was countered that adding prohibiting fertilizers and herbicides in the ordinance will at least educate people and there will be those who will comply and curb some of the uses. Regarding invasive grasses, in the section regarding reseeding, it was suggested to include wording that it be seeded with natural or native grass.

Relating back to the study, Chair Stead expressed he doesn't think there isn't much there. The biggest things they can do are limit runoff and provide natural buffers. Kelly Ranch Estates flows down to Bridge Creek.

B. Staff Report PL 14-88, An ordinance of the Homer City Council amending Homer City Code 21.70.010, Zoning permit required, and 21.90.030, Invalid land use permits, regarding the requirement for a zoning permit and the relationship of zoning violations to permit issuance

City Planner Abboud reviewed the staff report.

Chair Stead opened the public hearing. There were no public comments and the hearing was closed.

VENUTI/STROOZAS MOVED TO APPROVE THE DRAFT ORDINANCE AMENDING HCC 21.7.010 ZONING PERMITS REQUIRED AND 21.90.030 INVALID LAND USE PERMITS, REGARDING THE REQUIREMENT FOR A ZONING PERMIT AND THE RELATIONSHIP OF ZONING VIOLATIONS TO PERMIT ISSUANCE, AND FORWARD IT TO THE CITY COUNCIL FOR PUBLIC HEARING AND ADOPTION.

There was discussion that this seems to be pretty straight forward and that staff doesn't know if there will be any retroactive issues. There may be some discussion about it at the joint worksession with Council.

VOTE: NON OBJECTION: UNANIMOUS CONSENT.

Motion carried.

Plat Consideration

From: Julie Engebretsen
Sent: Wednesday, October 29, 2014 11:52 AM
To: Travis Brown
Subject: FW: Bridge Creek Watershed Ordinance
Attachments: Impervious Cover Documents.pdf

From: Bob Shavelson [mailto:bob@inletkeeper.org]
Sent: Thursday, October 16, 2014 12:47 PM
To: Rick Abboud
Cc: Julie Engebretsen
Subject: Bridge Creek Watershed Ordinance

Hi Rick -

Would you please forward this email to the Planning Commission and include in the record for the proposed revisions to the Bridge Creek Watershed Ordinance?

Thanks -

Bob

Dear Commissioners -

Thank you for the opportunity to testify last night on the proposed revisions to the Bridge Creek Watershed. Attached please find some literature on impervious cover that hopefully can help guide decision-making through this process.

In response to Commissioner Venuti's request, I will also be providing habitat and water quality data Inletkeeper has collected for the area in the near future.

A few points I would like to highlight from last night:

In response to Commissioner Stroozas question regarding the relative increase in impervious cover that would occur under the proposed ordinance, it's important to understand it's not the overall increase in impervious cover across the entire watershed, but rather the concentration of development in Kelly Ranch Estates which presents important questions. As noted during the Commission's discussion, runoff from Kelly Ranch Estates has a direct path to the Bridge Creek Reservoir, and it makes sense to understand the hydrology of that area and what effect best management practices might have on runoff should most or all of the lots in Kelly Ranch Estates get developed.

I emphasized again last night the importance of the Bridge Creek Watershed as Homer's sole drinking water source, and it's important to look down the road 20 or 50 years to think about what our actions now will do in the future. We cannot know whether all the lots will be developed, or whether some or many lots will be sub-divided and developed. Safe drinking water is and will increasingly be one of Homer's most valuable commodities, for residents, businesses and tourists alike. That's why it's so important to conduct hydrology studies so we base any decisions on the professional judgement and data of people skilled in this area.

Inletkeeper recognizes the arguments put forth by Mr. Story last night, and as mentioned, believes there are creative ways - through tax credits, sub-division scale mitigation measures and other tools - to address the issues raised by the concentration of lots in Kelly Ranch Estates. Along those lines, we're available to assist the Planning Department and the Commission in any way we can to help ensure we protect Homer's water supply while acknowledging property owner rights in the Bridge Creek Watershed District.

Thank you again for your time and work -

Bob

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3734 Ben Walters Lane
Homer, AK 99603
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Title:	Impervious surface coverage.
Authors:	Arnold Jr., Chester L. Gibbons, C. James
Source:	Journal of the American Planning Association. Spring96, Vol. 62 Issue 2, p243. 16p. 6 Diagrams, 2 Charts, 2 Graphs.
Document Type:	Article
Subject Terms:	*WATER quality management *URBAN planning
NAICS/Industry Codes:	237210 Land Subdivision 925120 Administration of Urban Planning and Community and Rural Development 924110 Administration of Air and Water Resource and Solid Waste Management Programs
Abstract:	Discusses various aspects of water resource protection in urban areas. Impervious land cover as an environmental indicator; Addressing of environmental issues; Land-use regulation; Natural resources planning in cities.
Full Text Word Count:	9367
ISSN:	0194-4363
Accession Number:	9604010765
Database:	Environment Complete

The Emergence of a Key Environmental Indicator

Planners concerned with water resource protection in urbanizing areas must deal with the adverse impacts of polluted runoff. Impervious surface coverage is a quantifiable land-use indicator that correlates closely with these impacts. Once the role and distribution of impervious coverage are understood, a wide range of strategies to reduce impervious surfaces and their impacts on water resources can be applied to community planning, site-level planning and design, and land use regulation. These strategies complement many current trends in planning, zoning, and landscape design that go beyond water pollution concerns to address the quality of life in a community.

Impervious land cover has long been characteristic of urban areas, but has only recently emerged as an environmental indicator. Natural resource planning using impervious surface coverage as a framework can be a pragmatic and effective way of addressing a host of complex urban environmental issues, particularly those related to the health of water resources.

Water resource protection at the local level is getting more complicated, largely due to the recognition of nonpoint source pollution, or polluted runoff, as a major problem. This diffuse form of pollution, now the nation's leading threat to water quality (Environmental Protection Agency 1994), is derived from contaminants washed off the surface of the land by stormwater runoff, and carried either directly or indirectly into waterways or groundwater. As programs directed at nonpoint source control cascade down from federal to state to local governments, the technical complexities involved with such control are further complicated by regulatory and management considerations.

Stormwater runoff problems are nothing new to local land-use decision-makers. However, the principal concern about runoff has always been safety, with the focus on directing and draining water off of paved surfaces as quickly and efficiently as possible. Once off the road and out of sight, stormwater has been largely out of mind--downstream consequences be damned (or dammed). Regulations have been expanded in recent years to include consideration of flooding and erosion, yet these factors fall far short of a comprehensive and effective approach to mitigating the water quality impacts of development.

How do planners and other local officials get a handle on protecting their local water resources? While no magic bullet exists to simplify all the complexities involved, an indicator is emerging from the scientific literature that appears to have all the earmarks of a useful tool for local planners--the amount of impervious, or impenetrable, surface. This article reviews the scientific underpinning, usefulness, and practical application of impervious surface coverage as an urban environmental indicator.

People, Pavement and Pollution

Impervious surfaces can be defined as any material that prevents the infiltration of water into the soil. While roads and rooftops are the most prevalent and easily identified types of impervious surface, other types include sidewalks, patios, bedrock outcrops, and compacted soil. As development alters the natural landscape, the percentage of the land covered by impervious surfaces increases.

Roofs and roads have been around for a long time, but the ubiquitous and impervious pavement we take for granted today is a relatively recent phenomenon. A nationwide road census showed that in 1904, 93 percent of the roads in America were unpaved (South-worth and Ben-Joseph 1995). This changed with the early twentieth century ascendancy of the automobile over the railways, capped by the mid-century massive construction of the interstate highway system, which served to both stimulate and facilitate the growth of suburbia. From that point on, imperviousness became synonymous with human presence--to the point that studies have shown that an areas's population density is correlated with its percentage of impervious cover (Stankowski 1972).

Impervious surfaces not only indicate urbanization, but also are major contributors to the environmental impacts of urbanization. As the natural landscape is paved over, a chain of events is initiated that typically ends in degraded water resources. This chain begins with alterations in the hydrologic cycle, the way that water is transported and stored.

These changes, depicted in figure 1, have long been understood by geologists and hydrologists. As impervious coverage increases, the velocity and volume of surface runoff increase, and there is a corresponding decrease in infiltration. The larger volume of runoff and the increased efficiency of water conveyance through pipes, gutters, and artificially straightened channels result in increased severity of flooding, with storm flows that are greater in volume and peak more rapidly than is the case in rural areas (Carter 1961; Anderson 1968; Leopold 1968; Tourbier and Westmacott 1981). The shift away from infiltration reduces groundwater recharge, lowering water tables. This both threatens water supplies and reduces the groundwater contribution to stream flow, which can result in intermittent or dry stream beds during low flow periods (Dunne and Leopold 1978; Harbor 1994).

Hydrologic disruption gives rise to physical and ecological impacts. Enhanced runoff causes increased erosion from construction sites, downstream areas and stream banks. The increased volume of water and sediment, combined with the "flashiness" of these peak discharges, result in wider and straighter stream channels (Arnold, Boison, and Patton 1982). Loss of tree cover leads to greater water temperature fluctuations, making the water warmer in the summer and colder in the winter (Galli 1991). There is substantial loss of both streamside (riparian) habitat through erosion, and in-stream habitat as the varied natural stream bed of pebbles, rock ledges, and deep pools is covered by a uniform blanket of eroded sand and silt (Schueler 1992). Engineered responses to flooding like stream diversion, channelization, damming, and piping further destroy stream beds and related habitats like ponds and wetlands. Finally, with more intensive land uses comes a corresponding increase in the generation of pollutants. Increased runoff serves to transport these pollutants directly into waterways, creating nonpoint source pollution, or polluted runoff.

Major categories of nonpoint source pollutants include pathogens (disease-causing microorganisms), nutrients, toxic contaminants, and debris. Pathogen contamination indicates possible health hazards, resulting in closed beaches and shellfish beds. Over-abundance of nutrients such as nitrogen and phosphorous can threaten well water supplies, and in surface waters can lead to algal "blooms" that, upon decaying, rob the waters of life-sustaining oxygen. Toxic contaminants like heavy metals and pesticides pose threats to the health of aquatic organisms and their human consumers, and are often persistent in the environment. Debris, particularly plastic, can be hazardous to animal and human alike, and is an aesthetic concern. Sediment is also a major nonpoint source pollutant, both for its effects on aquatic ecology and because of the fact that many of the other pollutants tend to adhere to eroded soil particles (Environmental Protection Agency 1992, 1993a).

The results of polluted runoff are evident in every corner of the United States. According to the Environmental Protection Agency (1994), nonpoint source pollution is now the number one cause of water quality impairment in the United States, accounting for the pollution of about 40% of all waters surveyed across the nation. The effects of nonpoint source pollution on coastal waters and their living resources have been of particular concern (U.S. House of Representatives 1988; Environmental Protection Agency 1993a). Urban runoff alone ranks as the second most common source of water pollution for lakes and estuaries nationwide, and the third most common source for rivers (Environmental Protection Agency 1994).

As point source pollution is increasingly brought under control, the true impact of urban nonpoint source pollution is being recognized. For instance, even in an urbanized estuary like Long Island Sound, where the major environmental problems have been strongly linked to point source discharges from sewage treatment plants, an estimated 47% of the pathogen contamination is from urban runoff (Long Island Sound Study 1994).

Imperviousness as an Environmental Indicator

Planners wishing to protect their community's water resources against these threats may not know where to begin. The site-specific and diffuse nature of polluted runoff seems to demand extensive technical information on pollutant loadings, hydrologic modeling, and the effectiveness of various management practices. This information is difficult to acquire, not only because of the cost of such studies, but because nonpoint-source-related research and engineering are new and evolving fields.

Enter impervious surfaces. When doing community-level planning, or where detailed site information is unavailable, impervious coverage may often be the most feasible and cost-effective vehicle for addressing water pollution. Two major factors argue for its potential utility to the local planner.

First, imperviousness is integrative. As such, it can estimate or predict cumulative water resource impacts without regard to specific factors, helping to cut through much of the intimidating complexity surrounding nonpoint source pollution. Although impervious surfaces do not generate pollution, they: (1) are a critical contributor to the hydrologic changes that degrade waterways; (2) are a major component of the intensive land uses that do generate pollution; (3) prevent natural pollutant processing in the soil by preventing percolation; and (4) serve as an efficient conveyance system transporting pollutants into the waterways. It is not surprising, then, that research from the past 15 years consistently shows a strong correlation between the imperviousness of a drainage basin and the health of its receiving stream (Klein 1979; Griffin 1980; Schueler 1987; Todd 1989; Schueler 1992; Booth and Reinfelt 1993; Schueler 1994a).

Figure 2 is a stylized graph of this general relationship, showing stream health decreasing with increasing impervious coverage of the watershed, or drainage basin, of the stream. The horizontal lines mark average threshold values of imperviousness at which degradation first occurs (10%), and at which degradation becomes so severe as to become almost unavoidable (30%). These thresholds serve to create three broad categories of stream health, which can be roughly characterized as "protected" (less than 10%), "impacted" (10%-30%), and "degraded" (over 30%).

Thresholds are always controversial and subject to change, yet it is important to note that to date, the threshold of initial degradation in particular seems to be remarkably consistent. The scientific literature includes studies evaluating stream health using many different criteria-pollutant loads, habitat quality, aquatic species diversity and abundance, and other factors. In a recent review of these studies, Schueler (1994a) concludes that "this research, conducted in many geographic areas, concentrating on many different variables, and employing widely different methods, has yielded a surprisingly similar conclusion--stream degradation occurs at relatively low levels of imperviousness (10-20%)" (100). Recent studies also suggest that this threshold applies to wetlands health. Hicks (1995) found a well-defined inverse relationship between freshwater wetland habitat quality and impervious surface area, with wetlands suffering impairment once the imperviousness of their local drainage basin exceeded 10%. Impervious coverage, then, is both a reliable and integrative indicator of the impact of development on water resources.

The second factor in favor of the use of imperviousness is that it is measurable. This enhances its utility both in planning and regulatory applications. (Examples follow in a later section.) Depending on the size of the area being considered and the particular application being applied, a wide range of techniques--with a wide range of price tags--exists for the measurement of impervious coverage.

For site level applications, on-site measurement using surveying equipment (sometimes as basic as a tape measure) is the most accurate and appropriate method. On the neighborhood level, "windshield" surveys may be appropriate where it is less important to have exact numbers. For community- or regional-scale areas, land cover derived from aerial photographs provides perhaps the best compromise between accuracy and cost. Finally, for applications encompassing even larger areas, remotely-sensed satellite-based land cover can be a viable option. At present, impervious estimates based on satellite data must be calculated by applying literature values of imperviousness to satellite land cover categories. We are currently involved with a remote sensing research project at the University of Connecticut that is attempting to devise a method for directly estimating imperviousness from satellite images (Civco and Arnold 1994).

It is important to note that all of these methods of measurement are increasingly being digitized and presented in the form of computerized maps in a geographic information system, or GIS. This trend eventually will make the information easier to acquire, often at lower expense. Many communities have been unable to afford GIS, and others have been disillusioned at its cost and complexity once they invested in it. Evolution of the technology, however, is making GIS more accessible to local officials every day.

The Components of Imperviousness

To measure and use impervious coverage as a tool for protecting water resources, it is necessary to know how imperviousness is distributed about the landscape. On a scale of increasing refinement, impervious coverage can be broken down by land use, by function within each land use, and by its relative impact on runoff. Each of these pieces of the puzzle can help to target planning and/or regulatory approaches to reducing impervious coverage. As with measurement techniques, the extent to which planners need detailed information on these components depends on the particular application.

The percentage of land covered by impervious surfaces varies significantly with land use. The most frequently cited estimates come from a report by the Soil Conservation Service (1975) (figure 3). "Strip" type commercial development tops the chart at around 95% coverage, with other business areas and industrial development lagging slightly behind. In residential areas, there is a wide range of imperviousness that varies predictably with lot size, going from about 20% in one-acre zoning to as high as 65% in one-eighth-acre zoning.

The City of Olympia, Washington, recently conducted a thorough study of impervious coverage in their area. For 11 sites measured, they found coverage values similar to the SCS values, finding four high-density residential developments (3-7 units/acre) to average 40% impervious, four multifamily developments (7-30 units/acre) to average 48% impervious, and three commercial/industrial sites to average 86% impervious coverage (City of Olympia 1995) (table 1).

In addition to the relationship between land use and the total amount of impervious coverage, studies show that all land uses are not equal with regard to the levels of contaminants present in the runoff. As noted, pollutant or land-use-specific studies are relatively new to the scientific community, but existing information supports the common-sense assumption that some land uses are more contaminating than others; for instance, runoff from gasoline stations contains extremely high levels of hydrocarbons and heavy metals (Schueler 1994b).

Recent research from Wisconsin goes one major step further, actually determining the pollutant concentrations from specific categories of impervious surfaces. Using micro-monitoring samplers that collected the runoff from 12 different types of surfaces (e.g., roofs, streets, parking lots, lawns, driveways) in residential, commercial, and industrial areas, Bannerman et al. (1993) were able to show distinct differences in the types and amounts of certain pollutants, depending on the source of the runoff. The study clearly identified streets as the impervious surfaces having the highest pollutant loads for most land-use categories (table 2). Roofs, with the exception of the zinc from industrial roofs, were generally low in pollutant loads, while parking lots had surprisingly moderate levels of pollutants. The one unpaved surface monitored, residential lawns, showed high levels of phosphorous, presumably from lawn and garden fertilizers. As this study is augmented by others over time, reliable relationships between pollutant loads and specific landscape components will undoubtedly emerge.

Impervious cover can be further broken down into its functional components. Schueler (1994a) and others point out the two major categories of impervious surface: rooftops, and the transport system (roads, parking lots, driveways, sidewalks). In general, the transport system is the dominant component, reinforcing the concept of an automobile-centric society. In the Olympia study, for instance, the transportation component ranged from 63% for single-family residential development to 70% for commercial development (City of Olympia 1995) (table 1).

One last refinement of the impervious component is its relationship in the landscape to surrounding areas, in the sense of how much of the rainfall onto a given surface is actually conveyed to a stream or stormwater collection system. In general, the rooftop component, which often drains to a lawn or other permeable areas, has less impact than roadways, which typically channel runoff directly to the stormwater system. The Olympia study (1994b) calls this factor the effectiveness at producing runoff, and estimates impervious areas in low-density residential developments to be about 40% effective, while those in commercial/industrial areas are close to 100% effective. In theory this concept could be applied to all surfaces--lawns themselves, for instance, can have a significant coefficient of runoff--but to our knowledge this level of refinement has not been researched, nor is it generally needed for most applications.

Imperviousness in Planning: A Framework, Some Examples

By considering the distribution of impervious cover by land use, function, and contribution to runoff, strategies begin to emerge for the reduction of both current and future levels of imperviousness. We suggest that these strategies can be grouped into three basic categories: community or regional planning; neighborhood and site planning, and regulation. Each category presents opportunities to revisit the status quo with an eye to water resource protection. Following are some general concepts and specific examples of such opportunities.

Planning at the Community or Regional Level

Land-use planning, even at the town level, need not be based on traditional political boundaries. Increasingly, environmental and natural resource professionals recommend planning based on the organization of natural systems (Environmental Protection Agency 1993c). Ecosystems as an organizational unit have been suggested, but the functional definition of an ecosystem remains elusive.

A more promising trend has been toward using watersheds as planning units (Environmental Protection Agency 1993b). A watershed, or drainage basin, is an area that drains to a common body of water, be it a lake, river, stream, aquifer, or bay. Watersheds have an advantage in that they can be clearly defined as geographic units. In addition, the watershed can be used as a system of organization at any number of scales, from a major basin encompassing several states, to a regional basin involving several municipalities, to a local sub-basin on the neighborhood level.

Thinking in terms of watersheds is particularly appropriate for stormwater management, which, after all, is all about drainage. At the University of Connecticut, we have developed a regional/community-level planning approach that provides an example of the use of both watersheds and impervious coverage. The Nonpoint Education for Municipal Officials (NEMO) project was initiated in 1991 to assist communities in dealing with the complexities of polluted runoff management (Arnold et al. 1993). The project, funded by the United States Department of Agriculture's Cooperative State Research, Education and Extension Service, is run by an interdisciplinary team that includes water quality, natural resource planning, and computer technology expertise. NEMO uses geographic information system (GIS) technology as a tool to educate local land-use decision-makers about the links between their town's land use and its water quality. Natural resource information on waterways and watersheds is combined with satellite-derived, land-cover information, and then displayed on colorful maps created with the GIS.

At the heart of NEMO is an analysis of impervious cover. Literature values for the percentage of impervious cover are applied to satellite land-cover categories to come up with rough estimates for the current level of imperviousness within a town or watershed. These values are averaged and displayed by local drainage basin (average area about one square mile) and categorized according to the protected/impacted/degraded scale of increasing impervious cover previously described and shown in figure 2. The current values are then contrasted with a zoning-based, build-out analysis of imperviousness, again displayed by local sub-basin (figure 4). The build-out allows town officials a look into the possible future of their town, not in conventional terms of population or lot coverage, but in terms of impervious cover--and by inference, the health of their local water resources.

The results of the impervious surface analysis can be used to help guide planning emphasis within each local basin area. For areas in the lower impervious zone, emphasis should be placed on preventive measures that retain existing natural systems, using techniques like open space planning and stream buffers. For areas that are in, or will be in, the "impacted" (1030%) zone, preventive planning should be accompanied by a focus on site design considerations that reduce runoff and imperviousness. Finally, for areas at (or climbing into) the "degraded" (over 30%) zone, the focus shifts to remediation through pollutant mitigation and resource restoration.

NEMO is one example of the use of imperviousness for broad-based community or regional water resource planning. Similar approaches are beginning to spring up around the country. Schueler (1994a) recommends watershed-based zoning that "is based on the premise that impervious cover is a superior measure to gauge the impacts of growth, compared to population density, dwelling units or other factors." In Alpine Township, Michigan, concern about the effects of urbanization on a formerly productive cold-water trout fishery has prompted researchers from Grand Valley State University to design a watershed-based GIS decision support system for local land-use authorities (Frye and Denning 1995). The system makes use of a number of hydrologic and land-use factors, including impervious surface estimates and zoning-based build-out analyses. In Montgomery County, Maryland, a detailed planning study was done to formulate a land-use strategy to protect the water resources of the Paint Branch stream (Montgomery County MD 1995). The study both measures and projects future impervious surface coverage by subwater-shed basin, and uses this information to help guide its recommendations for protective actions.

Each of these efforts contains the elements of impervious cover, subbasin-level analysis, and build-out projections. An even more comprehensive treatment is that undertaken by the City of Olympia, Washington. During 1993 and 1994, Olympia conducted their Impervious Surface Reduction Study (ISRS), from which information is cited repeatedly in this paper. The ISRS Final Report (City of Olympia 1995) contains an impressive and comprehensive body of research, policy analysis, and build-out scenarios, culminating in 19 specific action recommendations. The study concludes that "a 20% reduction [in future impervious cover] is a feasible and practical goal for Olympia and will not require exceptional changes in the Olympia community." The recommended reduction is equal to approximately 600 fewer acres of impervious coverage by the year 2012. Planners wishing to see an example of a comprehensive approach to reducing imperviousness would do well to read the Olympia ISRS report.

As with other natural resource protection efforts, community and watershed-level planning approaches like these are often the most effective way of achieving results. Addressing the issue at this scale provides an overall perspective and rationale for the design and regulatory tools described in the following sections. Site-level considerations are then based not only on the immediate impacts of a given development on the local stream or pond, but also on the site's incremental contribution to the pollution (or protection) of a larger-scale water body or aquifer. Review of site design and stormwater management plans, for instance, can be checked for consistency with goals for the appropriate watershed.

Providing this broad context has the added benefit of allowing for greater flexibility at the site level. Planners can evaluate individual factors like a site's location within the watershed, its land use, and the relative priority of the receiving stream as they relate to the overall plan, rather than applying a rigid and uniform set of requirements to all parcels.

Site-Level Planning

Site planning is perhaps the least-explored approach to reducing water pollution. Kendig (1980) states that "good design begins with an analysis of the natural and environmental assets and liabilities of a site," and that these factors should be the determinants of development patterns. Applying this principle to water resource protection translates to maintaining the natural hydrologic function of a site, through retaining natural contours and vegetation to the maximum extent possible. Consideration of impervious surface is a key element of this overall strategy, extending to all site-level considerations. These include construction practices, design that reduces imperviousness, and design that includes measures to mitigate the effects of the runoff from impervious areas.

Construction activity itself usually creates impervious surface, severely compacting earth with heavy machinery. Although erosion control practices may require procedures for limiting the area of exposed soil and how long it remains exposed, that requirement does not necessarily minimize the amount of compacted soil. Construction should be sequenced with this goal in mind, and it may be necessary later to loosen compacted areas and/or cover them with additional pervious materials (Craul 1995).

From construction, we move to reduction. For virtually all land uses, one of the best design-related opportunities for reducing imperviousness is through the reduction of road widths. As has been seen, roads both constitute a major fraction of a community's impervious coverage, and tend to produce the most pollutant-laden runoff.

The long-established concept of road hierarchies, which relates road size to the intensity of use, has many positive aspects beyond water quality, among them cost reductions and aesthetic benefits. Yet Southworth and Ben-Joseph (1995), in a recent article on the history of residential street design, found that, for a variety of historical and institutional reasons, road hierarchies are often overlooked by local planners and commissions. The authors conclude that an over-emphasis on traffic control has resulted in a "rigid, over-engineered approach . . . deeply embedded in engineering and design practice." Simple math dictates that for a given length of subdivision road, reduction from a typical 32-foot to a 20-foot width results in a 37.5% reduction in pavement, or over 63,000 square feet (about one and one-half acres) per linear mile. The Olympia study estimated that changing the width of local access roads from 32 to 20 feet would result in an overall 6% reduction in imperviousness for a given development site in their region, that is, six acres less street pavement for a typical 100-acre subdivision (City of Olympia 1994b).

Road surface reduction is a primary reason why clustering is the most pavement-stingy residential design. Large-lot subdivisions, which have long been recognized as being antithetical to most conservation goals (Arendt 1994a, 1994b) generally create more impervious surface and greater water resource impacts than cluster-style housing does. This is true even though the large lots may have less impervious coverage per lot, because the attenuated design requires longer roads, driveways, and sidewalks, which make the overall subdivision parcel more impervious (figure 5). Schueler (1994c) states that cluster development can reduce site imperviousness by 10-50%, depending on lot size and the road network.

In commercial and industrial zones, the focus of design-related reductions in imperviousness shifts to parking areas, the largest component of impervious cover (table 1). Research has shown oversupply of parking to be the rule. Willson (1995), citing his research and that of many others, found that the "golden rule" of 4.0 parking spaces per 1,000 square feet of office floor space is often almost twice what is actually needed. Using a generic, medium-sized office building as a hypothetical example, he shows that a typical parking supply ratio of 3.8 results in an extra 55,000 square feet of parking lot, compared to using a more factually-based ratio of 2.5.

The City of Olympia found not only parking oversupply, with vacancy rates of 60-70%, but also developers consistently building parking above minimum ratios, with 51% more parking spaces at their 15 survey sites than were required by zoning (City of Olympia 1994c). This agrees with our observation that, at least in Connecticut, overbuilding of parking appears to be a recent trend with "big box" retail store developers, who typically require at least 5 spaces per 1,000 square feet, principally to meet peak demands on weekends and during the busy period from Thanksgiving to Christmas.

Reductions in parking-related impervious cover-age can be attained in ways other than adjusting parking supply ratios. Shoup (1995) suggests that parking can be reduced through economic incentives that effectively end the subsidy provided by employer-paid parking. Employee commuter option programs, mandated by the Clean Air Act Amendments of 1990 in areas of "severe nonattainment" for ozone standards, hold some promise for reducing parking demand. The Olympia study (City of Olympia 1994d) concluded that sharing, joining, or coordinating parking facilities can reduce parking significantly. Finally, vertical garages (above or below ground) can be encouraged, although this alternative can be expensive. Many of these strategies were recently combined in an innovative office park design in Lacey, Washington, where the new 360,000-square-foot headquarters of the state Department of Ecology was designed around a "parking diet" that slashed parking spaces from 1500 to 730 (Untermann 1995).

Imperviousness also has a role in design related to mitigation of polluted runoff. "Best management practices" (BMPs) is the most commonly-used term to describe the wide range of on-site options available to manage stormwater runoff. BMPs are often divided into two major types: those involving structures such as stormwater detention ponds or infiltration trenches, and "nonstructural" practices that usually involve use of vegetated areas to buffer, direct, and otherwise break up the sea of asphalt. Maintenance measures like road sand sweeping and storm drain cleaning are also included.

It is not within the scope of this article to give a thorough discussion of these practices; choosing the correct assemblage is a combination of art and science, and involves many considerations. From the standpoint of imperviousness, however, BMPs can be viewed in terms of how well they replicate the natural hydrological functioning of the site. This perspective puts a premium on restoring infiltration, which has been suggested by Ferguson (1994) and others to be highly preferable to surface detention.

Emphasizing infiltration and nonstructural solutions often comes into conflict with established development practices. Curbing is a good example. Just as Southworth and Ben-Joseph (1995) found the over-engineering of road widths to be ingrained in local practice, our experience has been that to many town engineers, the necessity of curbing is a given. Safety and structural integrity of the road are often given as reasons for curbing, above and beyond its drainage function. Highway engineers in our state, however, have told us that the sole purpose of curbing is to direct stormwater, and even then, it is only truly needed during the unstable construction phase (Connecticut Department of Transportation 1995). In many cases, more pervious alternatives to directing runoff should be investigated. Grassy swales, for instance, might be constructed in the margin created when existing right-of-way widths are retained while road widths are reduced.

Mitigating the impacts of polluted runoff in the "ultra-urban" inner city environment is a particularly thorny issue. Regional approaches like the Olympia ISRS may target these areas for increased impervious cover (City of Olympia 1994a). Growth policies that encourage urban "infilling" may result in higher inner-city imperviousness in order to reduce sprawl and overall imperviousness, region-wide. In effect, this is "clustering" on a regional scale.

Nonetheless, even for these seemingly intractable areas, using imperviousness as a planning framework can be useful. Usually, this involves linking the reduction of impervious surfaces to complementary urban initiatives. Parking is one example. Excess parking can be attacked from many angles other than water quality, including air quality, traffic congestion, promotion of sprawl, and inefficient use of building lots. A parking reduction initiative could be combined with a plan to use the recouped paved area either for active stormwater treatment (infiltration basins, detention ponds) or for more modest stormwater management (vegetated strips). Such a strategy could be combined with the creation of "vest pocket" parks and other green spaces, shown by urban forestry research as having positive sociological and psychological effects on city dwellers (Gobster 1992; Schroeder and Lewis 1992).

Research on the pollutant-processing capability of various types of vegetation suggests a slight twist on parking lot design that may reap large benefits in water quality for urban areas. Parking lots often incorporate landscaped areas, usually in raised beds surrounded by asphalt curbing. However, these vegetated areas can be planted below the level of the parking surface, serving as infiltration and treatment areas for runoff (Bitter and Bowers 1994) (figure 6). This idea can be extended to other areas where vegetated "islands" are traditionally used, such as in the middle of cul-de-sac circles.

Another consideration for urbanized areas is pervious alternatives to pavement. This includes various mixes of asphalt with larger pore spaces (e.g., "popcorn" mix), and alternative systems such as open-framework concrete pavers filled with sand or gravel, or turf reinforced with plastic rings. These systems can become clogged with sediment, particularly during construction, but are often a suitable alternative in low traffic areas like emergency roads, driveways, and overflow parking areas. Cahill (1994) asserts that, contrary to common belief, pervious pavement can be used successfully in many places if certain siting, construction, and maintenance practices are followed; for instance, he recommends vacuum cleaning at least twice per year. Granular surfacings are being promoted by some landscape architects as attractive, inexpensive, and more aesthetically-pleasing alternatives to paved pathways and trails (Sorvig 1995).

One last important note about reducing imperviousness through planning and design-it can save money. Savings to both the private and public sectors in reduced construction and infrastructure costs can be considerable. For instance, a recent study done for the Delaware Estuary Program compared the impacts on twelve communities in the watershed, over a 25-year horizon, of a continuation of current "sprawl" development patterns versus the Program-recommended pattern of promoting mixed uses, open space, and growth around existing centers. They concluded that for these communities, the less consumptive pattern resulted in savings of $28.8 million in local road costs, $9.1 million in annual water treatment costs, $8.3 million in annual sewer treatment costs, as well as an 8.4% reduction in overall housing costs, and a 6.9% savings in annual costs of local public-sector services (Burchell, Dolphin, and Moskowitz 1995).

The Use of Imperviousness for Regulation

Planning approaches at the community and site level can be complemented with specific applications that give regulatory teeth to planning objectives. To begin with, planners can revisit their current zoning and subdivision requirements with an eye to imperviousness. For instance, many lot coverage limits, particularly for residential uses, refer to rooftops but do not include parking space, sidewalks, and driveway coverage.

Impervious cover lends itself well to zoning that uses performance standards. In fact, Kendig (1980) defines performance zoning as that which regulates development on the basis of four fundamental measures of land-use intensity, one of which is the impervious surface ratio. Jaffe (1993), in a critical assessment of performance-based zoning, concludes that "Kendig's recreational and impervious surface ratios are especially effective in achieving local environmental objectives for stormwater management and groundwater recharge." Performance zoning has the added effect of encouraging mixed uses, which generally result in less impervious coverage and less pollution, by reducing roads and vehicle traffic.

Community-wide applications encompassing large areas with varied land use will require sliding scales of impervious coverage limits that depend on the location, size, and type of use. Such standards have been in place in some Florida communities for almost a decade (American Planning Association Zoning News 1989). More recently, ordinances limiting impervious cover have been enacted in Austin and San Antonio, Texas, driven by concern about pollution of the area's major drinking water aquifer (City of Austin 1992; City of San Antonio 1995).

In instances where protection of a particularly important resource is desired, strict limits on impervious coverage may be imposed. Such is the case in Brunswick, Maine, where a "coastal protection" zone was created for areas draining to Maquoit Bay, site of shellfish beds critically important to the town. The special zone has certain stringent performance standards, among them a maximum impervious-surface lot coverage of 5%. This coverage includes ". . . buildings, roads, driveways, parking areas, patios, and other similar surfaces" (Town of Brunswick 1991).

In this case, the very low impervious limit was feasible because the total area affected was fairly small, the use was largely residential, and the specific pollutant of concern was nitrogen emanating from septic systems, resulting in zoning that called for a minimum lot size of one unit per five acres. This "down-zoning" approach, which has also been used in the Buttermilk Bay area in Massachusetts (Horsley and Witten 1991), is practicable for small areas with septic-related concerns, but if applied over large areas, can lead in the long run to promotion of sprawl.

Strict limits may be appropriate, yet in practice they can result in the need for complicated exemption provisions, or even raise the specter of private property rights takings (Land Use Law and Zoning Digest 1995; Ross 1995; Settle, Washburn, and Wolfe 1995). One method for "softening" the concept of limits is to allow for flexibility on the site level. In this scenario, an ordinance setting a limit (or goal) for a site's impervious coverage would require more stringent on-site stormwater treatment when the limit is exceeded. This type of approach will undoubtedly become more common as the information base on removal efficiencies of various treatment measures expands. Another type of flexibility comes from applying performance standards to specific elements of imperviousness within the landscape, In their discussion of next steps, the Olympia study (City Of Olympia 1995) cites the development of performance-based standards for sidewalks, parking, and landscaping "to encourage innovation and provide flexibility in meeting impervious surface reduction goals."

One practical regulatory application of impervious coverage is for stormwater utility assessment, an "impact fee" that is growing in use in urban areas of the country as a way of paying for the treatment and control of polluted runoff. Impervious surface has long been a key determinant in mathematical models that predict the volume of runoff from a given piece of land. Stormwater utility assessments have taken the lead from these models in using imperviousness as a basis for a utility rate structure that fairly distributes the cost of treatment according to a property's contribution to runoff.

Such systems are now in place in many areas, including Kansas City, Missouri; Kitsap County, Washington; and throughout the state of Florida. This type of application requires a community-wide assessment of impervious coverage, and a wide range of techniques is being used. In Kansas City, rate structures are based on digitized high-resolution orthorectified aerial photos (Murphy 1995), while in Florida they are based on statistical surveys of area lots (Livingston 1995). The Kitsap County, Washington, Comprehensive Surface and Stormwater Management Program, established in 1994, creates a rate structure based on an "equivalent service unit" equal to the average estimated amount of impervious surface area on a single-family residential parcel (Kitsap County 1994).

Such programs not only raise funds for mitigation of adverse impacts, but also, by attaching a cost to imperviousness, provide an economic incentive to reduce it. Apparently, this effect is beginning to be seen in Florida, where the cost savings associated with lower stormwater utility fees have provided the impetus for reduction of impervious cover during site redevelopment (Livingston 1995).

Integrating Stormwater Control into Community Planning

The strategies described above demonstrate that for the planner, imperviousness can provide a useful framework .for addressing the impacts of urbanization on water resources. But the advantage of this approach goes beyond any specific application. We have found that working with a town on water resource protection often leads to related natural resource issues like open space preservation and forest management. Our recent experience with NEMO has taught us that framing water issues largely in terms of imperviousness serves to expand the range of these connections.

Once water pollution is linked to impervious coverage and its various components, it has a way of insinuating itself into issues currently "on the table" in town. Road widths and curbing may be subjects of town debate about cost or neighborhood character. Parking and landscaping requirements for commercial zones may be undergoing reexamination for aesthetic reasons. The appropriateness of "big box" retailers may be a hot topic, with arguments centered around traffic congestion and the impact on local merchants. An open space plan may be in the formative stages, or the use of stream buffers being questioned. Citizens may be interested in naturalistic landscaping, water conservation, or volunteer monitoring of local waterways. These typical local debates, drawn from towns working with the NEMO Project, now have elements of water quality and impervious surface reduction as part of the mix. And through these debates, the subject of water quality in the community is extended beyond land-use-related staff and boards to include engineering and public works departments, land trusts and other nonprofits, and citizens.

Cross connections of this type are an important key to ensuring the implementation of any planning initiative. For the professional planner, they create opportunities to reinforce complementary planning concepts from several different angles. Beyond the well-established concept of planning and designing with nature (McHarg 1969), there are many relatively recent themes in transportation, subdivision design, and landscape architecture that go hand-in-glove with the reduction of impervious surfaces. Performance zoning is one example. Another is neotraditional residential design, which champions styles of development patterned after the traditional New England village in order to foster a sense of community (Duany and Plater-Zyberk 1991). The open space subdivision designs promoted by Arendt (1994b) for land conservation age also a good fit. On another front, residential street layouts promoting "traffic calming" for a variety of safety, aesthetic, and sociological benefits (Hoyle 1995; Ben-Joseph 1995) could easily incorporate pavement reduction. Landscape architects are calling for more naturalistic schemes that follow. the natural contours and make use of low-maintenance, drought-resistant plants (Ash 1995). Planners should seize the opportunity to "piggy-back" water quality with these complementary initiatives, making sure to explicitly incorporate the reduction of paved surfaces and their impacts into official policy, plans, and procedures.

The other advantage of the cross-cutting nature of water resource protection in general, and imperviousness specifically, is that it seems to make sense to the average citizen. Reduction of paved areas is one of relatively few planning initiatives that "plays" at all levels, from the suburban driveway to the big box parking lot, and even to the Chief Justice of the Supreme Court, who recognized the link between the growth of paved surfaces and increased runoff (in Dolan v. City of Tigard) (Merriam 1995).

From our standpoint as educators, this feature is critical to the success of any local planning initiative. Education of citizens and local officials on the issues is a necessary and integral part of the process of changing land-use procedures. Volunteer commissioners on local land-use boards are particularly important. In our experience, almost any narrowly-framed issue or problem (environmental or otherwise) brought before busy city, town, or county boards is already operating with two strikes against it. Few issues are isolated, yet they are frequently presented to communities as such, reflecting not the nature of community planning but that of regulatory agencies. A regional planner we work with has called this the "environmental flavor of the month" syndrome.

The result is that even legally mandated initiatives may be doomed to failure by the sheer inertia involved in integrating new and complex information into the busy world of local land-use decision-making. Framing the issue of nonpoint source pollution in terms of imperviousness, although it may be a bit simplistic, appears to be an effective way of enabling local decision-makers to grasp the issue sufficiently to take action.

Conclusion

Water pollution is getting more complex, while at the same time the responsibility for water resource protection is shifting toward local authorities. The use of impervious surface coverage as an environmental indicator can assist planners to construct a game plan to protect their community's natural resources.

Imperviousness integrates the impacts of development on water resources, so it can help to cut through much of the complexity. It is measurable, and so appropriate for a wide range of planning and regulatory applications. It is a cross-cutting feature that is a frequently hidden, but nonetheless substantial, component of many current trends in road, neighborhood, and landscape design, so it can be used as a reinforcing connection between seemingly unrelated planning initiatives. Finally, the basic tenets of reducing imperviousness--retaining the natural landscape, minimizing pavement, promoting infiltration to the soil--are simple concepts that can be understood by a community and its residents.

Impervious cover is rarely specifically identified or addressed in community goals, policies, or regulations. It should be. In this article, we have tried to facilitate the use of this indicator by (1) reviewing the scientific literature to provide a comfort level with its appropriateness; (2) creating a framework for its use in overall planning, site-level planning, and regulation; and (3) providing real-world examples of such applications. With imperviousness as a foundation, planning that begins with water resources often leads to character, design, and aesthetic issues that, taken together, define much of the overall quality of life in a community.

TABLE 1. Site coverage for three land uses in Olympia, Washington

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Legend for Chart:

A - Surface Coverage Type
B - Average Approximate Site Coverage, % High Density
    Residential (3-7 units/acre)
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C - Multifamily (7-30 units/acre)
D - Commercial

A	B	C	D
1. Streets	16	11	03
2. Sidewalks	03	05	04
3. Parking/driveways	06	15	53
4. Roofs	15	17	26
5. Lawns/landscaping	54	19	13
6. Open space	n/a	34	n/a
Total impervious surface (1-4)	40	48	86
Road-related impervious surface (1-3)	25	31	60
(Road-related as a percentage of total impervious coverage)	(63%)	(65%)	(70%)

Adapted from City of Olympia 1995

TABLE 2. Surfaces exhibiting highest levels of runoff-borne pollutants, out of twelve surface types sampled in selected urban areas in Wisconsin

Legend for Chart:

A - POLLUTANT
B - Highest levels
C - SURFACE Second highest levels
D - Third highest levels

A	B C D
e. coli (pathogens)	residential feeder streets residential collector streets residential lawns
solids (sediment)	industrial collector streets industrial arterial streets residential feeder streets
total phosphorous	residential lawns industrial collector streets residential feeder streets
zinc	industrial roofs industrial arterial streets commercial arterial streets
cadmium	industrial collector streets industrial arterial streets commercial arterial streets
copper	industrial collector streets industrial arterial streets

residential collector streets

Adapted from Schueler 1994d

FIGURE 3. Average percentage of impervious coverage by land use Source: Soil Conservation Service 1975

Residential Lot Size (acres)	Percent Impervisions
1	20
1/2	25
1/3	30
1/4	38
1/8	65
INDUSTRIAL	75
COMMERCIAL	85
SHOPPING CENTERS	95

PHOTO (BLACK & WHITE): FIGURE 1. Water cycle changes associated with urbanization Source: Environmental Protection Agency 1993a

GRAPH: FIGURE 2. Stylized relationship of imperviousness to stream health Modified from Schueler 1992

MAP: FIGURE 4. Impervious coverage analysis for Old Saybrook, CT

DIAGRAM: FIGURE 5. Clustering reduces overall site imperviousness. Source: John Alexopoulos, University of Connecticut

PHOTO (BLACK & WHITE): FIGURE 6. Sunken vegetated parking lot "islands" intercept and treat runoff. Source: John Alexopoulos, University of Connecticut

REFERENCES

Anderson, D. G. 1968. Effects of Urban Development on Floods in Northern Virginia. U.S. Geological Survey Open-File Report.

APA Zoning News. 1989. New Techniques for Controlling Stormwater Pollution. May.

Arendt, Randall. 1994a. Rural by Design: Maintaining Small Town Character. Chicago, IL: APA Planners Press.

Arendt, Randall. 1994b. Designing Open Space Subdivisions: A Practical Step-By-Step Approach. Media, PA: Natural Lands Trust, Inc.

Arnold, C. L., P. J. Boison and P. C. Patton. 1982. Sawmill Brook: An Example of Rapid Geomorphic Change Related to Urbanization. Journal of Geology 90, 2: 155-66.

Arnold, C. L., H. M. Crawford, C. J. Gibbons, and R. F. Jeffrey. 1994. The Use of Geographic Information System Images as a Tool to Educate Local Officials about the Land Use/Water Quality Connection. In Proceedings of the Watersheds '93 Conference, Alexandria, Virginia, March 1993. 373-7.

Ash, Tom. 1995. Low-Maintenance Landscapes. Landscape Architecture 85, 9: 136.

Bannerman, R. T., D. W. Owens, R. B. Dodds and N. J. Hornewer. 1993. Sources of Pollutants in Wisconsin Stormwater. Water Science and Technology 28, 3-5: 241-59.

Ben-Joseph, Eran. 1995. Changing the Residential Street Scene: Adapting the Shared Street (Woonerf) Concept to the Suburban Environment. Journal of the American Planning Association 61, 4: 505-15.

Bitter, Susan D., and J. Keith Bowers. 1994. Bioretention as a Water Quality Best Management Practice. Watershed Protection Techniques 1, 3: 114-6.

Booth, Derek B., and Lorin E. Reinfelt. 1993. Consequences of Urbanization on Aquatic Systems--Measured Effects, Degradation Thresholds, and Corrective Strategies. In Proceedings of the Watershed '93 Conference, Alexandria, Virginia, March 1993. 545-50.

Burchell, Robert W., William Dolphin, and Harvey S. Moskowitz. 1995. Impact Assessment of DELEP CCMP versus Status Quo on Twelve Municipalities in the DE-LEP Region. Report #95-06 of the Delaware Estuary Program.

Cahill, Thomas. 1994. A Second Look at Porous Pavement/ Underground Recharge. Watershed Protection Techniques 1, 2: 76-8.

Carter, R. W. 1961. Magnitude and Frequency of Floods in Suburban Areas. In Short Papers in the Geologic and Hydro-logic Sciences. U.S. Geological Survey Professional Paper 424-B: B9-B11.

City of Austin, Texas. 1992. An Ordinance Codifying the "Save Our Springs" Ordinance as Approved by the Qualified Voters of the City on August 8, 1992.

City of Olympia, Washington. 1994a. Impervious Surface Reduction Study: Technical and Policy Analysis Final Report. City of Olympia Public Works Department.

City of Olympia, Washington. 1994b. Impervious Surface Reduction Study: Impervious Surface Coverage Evaluation: A Basin and Site Coverage Assessment. City of Olympia Public Works Department.

City of Olympia, Washington. 1994c. Impervious Surface Reduction Study: Special Parking Capacity Study. City of Olympia Public Works Department.

City of Olympia, Washington. 1994d. Impervious Surface Reduction Study: Shared Parking Survey of Local Jurisdictions Summary. City of Olympia Public Works Department.

City of Olympia, Washington. 1995. Impervious Surface Reduction Study: Final Report. City of Olympia Public Works Department.

City of San Antonio, Texas. 1995. An Ordinance Amending Chapter 34, Article VI of the City Code By Adding a New Division 6 Thereunder Entitled "Aquifer Recharge Zone and Watershed Protection."

Civco, Daniel L., and C. L. Arnold. 1994. Land Use and Land Cover Mapping for the Connecticut and New York Portions of the Long Island Sound Watershed. Grant Proposal to the Long Island Sound Research Fund of the Connecticut Department of Environmental Protection.

Connecticut Department of Transportation (several staff members). 1995. Personal communication.

Craul, Phillip. 1995. Reducing Soil Compaction. Landscape Architecture 84, 12: 34-6.

Duany, Andres, and Elizabeth Plater-Zyberk. 1991. Towns and Town-Making Principles. Cambridge, MA: Harvard University School of Design.

Dunne, Thomas, and Luna B. Leopold. 1978. Water in Environmental Planning. San Francisco, CA: W. H. Freeman and Company.

Environmental Protection Agency. 1992. Managing Non-point Source Pollution: Final Report to Congress on Section 319 of the Clean Water Act. United States Environmental Protection Agency #EPA-506/9-90. Washington, DC: USEPA Office of Water.

Environmental Protection Agency. 1993a. Guidance Specifying Management Measures for Sources of Nonpoint Source Pollution in Coastal Waters. United States Environmental Protection Agency #840-B-92-002. Washington, DC: USEPA Office of Water.

Environmental Protection Agency. 1993b. The Watershed Protection Approach: Annual Report 1992. United States Environmental Protection Agency #EPA840-S-93-001. Washington, DC: USEPA Office of Water.

Environmental Protection Agency. 1993c. Geographic Targeting: Selected State Examples. United States Environmental Protection Agency #EPA-841-B-93-001. Washington, DC: USEPA Office of Water.

Environmental Protection Agency. 1994. The Quality of Our Nation's Water: 1992. United States Environmental Protection Agency #EPA-841-S-94-002. Washington, DC: USEPA Office of Water.

Ferguson, Bruce K. 1994. Stormwater Infiltration. Boca Raton, FL: Lewis Publishers, CRC Press, Inc.

Frye, Ed, and Rod Denning. 1995. Michigan Township Uses Watershed-Based Decision-Support System. Geo Info Systems 5, 9: 55-7.

Galli, F. J. 1991. Thermal Impacts Associated with Urbanization and Stormwater Management Best Management Practices. Washington, DC: Metropolitan Washington Council of Governments/Maryland Department of Environment.

Gobster, Paul. 1992. Social Benefits and Costs of Enhancing Biodiversity in Urban Forests. In Alliances for Community Trees: Proceedings of the Fifth National Urban Forest Conference,

Los Angeles, California, November 12-17, 1991. 62-5.

Griffin, D. M. 1980. Analysis of Non-Point Pollution Export from Small Catchments. Journal of the Water Pollution Control Federation 52, 4: 780-90.

Harbor, Jonathan M. 1994. A Practical Method for Estimating the Impact of Land Use Change on Surface Runoff, Groundwater Recharge and Wetland Hydrology. Journal of the American Planning Association 60, 1: 95-108.

Hicks, Anna L. 1995. Impervious Surface Area and Benthic Macroinvertebrate Response as an Index of Impact from Urbanization on Freshwater Wetlands. Unpublished MS Thesis, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA.

Horsley and Witten, Inc. 1991. Quantification and Control of Nitrogen Inputs to Buttermilk Bay, Massachusetts. Report to the Buzzards Bay National Estuary Program. Barnstable, MA: Horsley and Witten, Inc.

Hoyle, Cynthia L. 1995. Traffic Calming. American Planning Association Planning Advisory Service Report Number 456.

Jaffe, Martin. 1993. Performance Zoning: A Reassessment. Land Use Law (March): 3-9.

Kendig, Lane. 1980. Performance Zoning. Washington, DC: Planners Press, American Planning Association.

Kitsap County, Washington. 1994. Kitsap County Comprehensive Surface and Stormwater Management Program.

Klein, R. D. 1979. Urbanization and Stream Quality Impairment. Water Resources Bulletin 15, 4: 948-63.

Land Use Law and Zoning Digest. 1995. Maryland Appeals Court Rules that Watershed Protection Zoning Does Not Cause Unconstitutional Taking. Land Use Law & Zoning Digest 47, 9: 13-4.

Leopold, L. B. 1968. Hydrology for Urban Land Use Planning: A Guidebook on the Hydrologic Effects of Urban Land Use. U.S. Geological Survey Circular 554.

Livingston, Eric. 1995. Tallahassee, FL: Florida Department of Environmental Protection. Personal communication.

Long Island Sound Study. 1994. The Comprehensive Conservation and Management Plan for Long Island Sound. Stamford, CT: Long Island Sound Office of the Environmental Protection Agency.

McHarg, Ian L. 1969. Design with Nature. Garden City, NY: The Natural History Press.

Merriam, Dwight. 1995. Hartford, CT: Robinson and Cole. Personal communication.

Montgomery County, Maryland. 1995. Upper Paint Branch Watershed Planning Study: Final Draft. Silver Spring, MD: Maryland-National Capital Park and Planning Commission of the Montgomery County Planning Department.

Murphy, Scott. 1995. Kansas City Builds GIS to Defray Costs of Clean Water Act Compliance. Geo Info Systems 5, 6: 39-41.

Ross, D. Lauren. 1995. Barton Springs Water Protection Efforts Challenged. Nonpoint Source News-Notes 42: 13-5.

Schroeder, Herbert, and Charles Lewis. 1992. Psychological Benefits and Costs of Urban Forests. In Alliances for Community Trees: Proceedings of the Fifth National Urban Forest Conference, Los Angeles, California, November 12-17, 1991. 66-8.

Schueler, T. R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Publication #87703 of the Washington Metropolitan Council of Governments.

Schueler, T. R. 1992. Mitigating the Adverse Impacts of Urbanization on Streams: A Comprehensive Strategy for Local Government. In Watershed Restoration Sourcebook. Publication #92701 of the Metropolitan Washington Council of Governments, edited by P. Kumble and T. Schueler.

Schueler, T. R. 1994a. The Importance of Imperviousness. Watershed Protection Techniques 1, 3: 100-11.

Schueler, T. R. 1994b. Hydrocarbon Hotspots in the Urban Landscape: Can They Be Controlled? Watershed Protection Techniques 1, 1: 3-5.

Schueler, T. R. 1994c. Use of Cluster Development to Protect Watersheds. Watershed Protection Techniques 1, 3: 137-40.

Schueler, T. R. 1994d. Sources of Urban Stormwater Pollutants Defined in Wisconsin. Watershed Protection Techniques 1, 1: 30-1.

Settle, Richard L., J. T. Washburn, and C. R. Wolfe. 1995. Washington State Regulatory Reform: Jekyll and Hyde '95. Land Use Law & Zoning Digest 47, 9: 3-7.

Shoup, Donald C. 1995. An Opportunity to Reduce Minimum Parking Requirements. Journal of the American Planning Association 61, 1: 14-28.

Soil Conservation Service. 1975. Urban Hydrology for Small Watersheds. USDA Soil Conservation Service Technical Release No. 55, Washington, DC.

Sorvig, Kim. 1995. The Path Less Traveled. Landscape Architecture 84, 12: 30-3.

Southworth, Michael, and Eran Ben-Joseph. 1995. Street Standards and the Shaping of Suburbia. Journal of the American Planning Association 61, 1: 65-81.

Stankowski, S. J. 1972. Population Density as An Indirect Indicator of Urban and Suburban Land-surface Modifications. U.S. Geological Survey Professional Paper 800-B: B219-B224.

Todd, David A. 1989. Impact of Land Use and Nonpoint Source Loads on Lake Quality. Journal of Environmental Engineering 115, 3: 633-49.

Tourbier, J. T., and R. Westmacott. 1981. Water Resources Protection Technology: A Handbook of Measures to Protect Water Resources in Land Development. Washington, DC: The Urban Land Institute.

Town of Brunswick, Maine. 1991. An Ordinance Creating a Coastal Protection Zone, effective August 20, 1991.

United States House of Representatives. 1988. Coastal Waters in Jeopardy: Reversing the Decline and Protecting America's Coastal Resources. In Oversight Report of the Subcommittee on Fisheries and Wildlife Conservation and the Environment and the Subcommittee on Oceanography of the Committee on Merchant Marine and Fisheries.

Untermann, Richard K. 1995. Office Park Paradise. Landscape Architecture 85, 8: 120.

Willson, Richard W. 1995. Suburban Parking Requirements: A Tacit Policy for Automobile Use and Sprawl. Journal of the American Planning Association 61, 1: 29-42.

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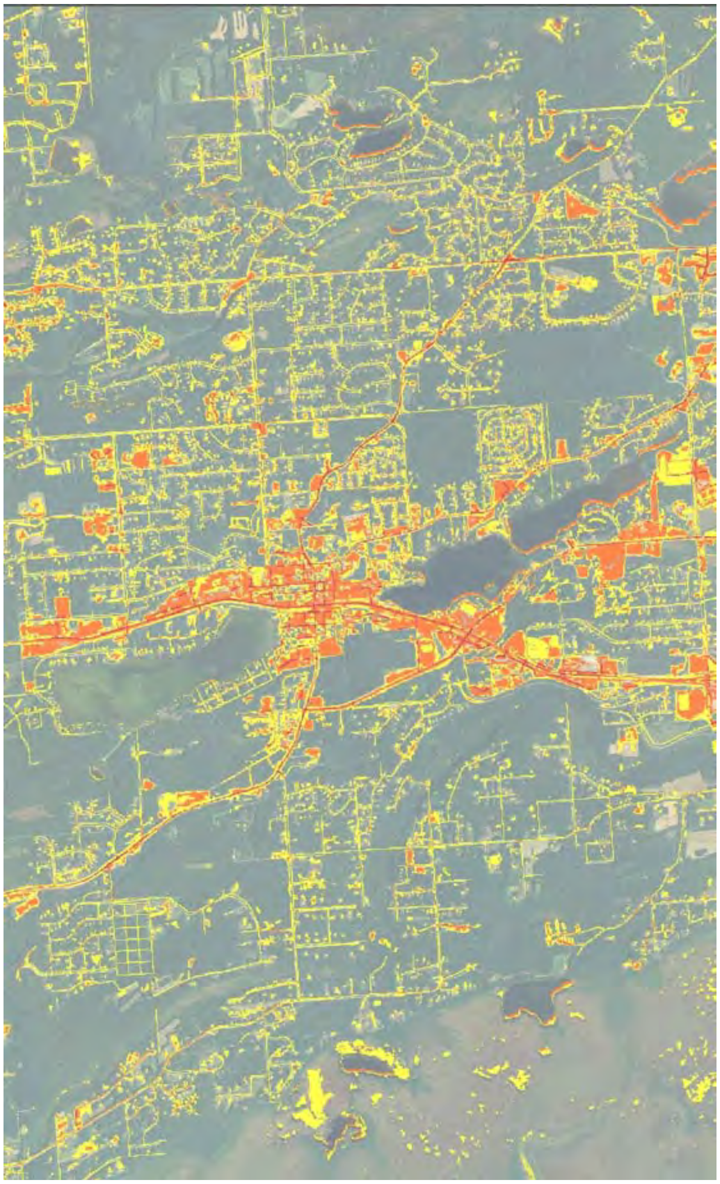

Mapping Impervious Surfaces in the Mat-Su

Measuring Development at the Subwatershed Scale

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The Nature Conservancy
Anchorage, Alaska

November 2011

QUESTION: How has impervious surface changed across the Matanuska-Susitna basin during the past decade of rapid population growth?

Research has shown that increased impervious cover levels can negatively impact water quality and flows leading to degraded stream health for fish (Schueler, R.,et.al; 2009). The Matanuska-Susitna Salmon Partnership identified minimizing impervious surfaces and their resultant storm water runoff as an objective in the Partnership's Strategic Action Plan (MatSu Salmon, 2008). Additionally, the release of 2010 Census data confirmed the Mat-Su Borough as Alaska's fastest growing region which further strengthened the need for a study of impervious surfaces (US Census, 2011).

METHODS: What are the most appropriate means to generate an updated impervious surface dataset of the highest accuracy and precision using existing source data and within the project budget?

Prior to this project, the US Geological Survey's (USGS) National Land Cover Dataset (NLCD) imperviousness layer functioned as the only basin wide baseline. The USGS generated this layer using LANDSAT satellite imagery from the years 1999-2001. While this dataset is of a relatively coarse nature with 30 meter pixels, it does characterize the relative extent of development within the region approximately one decade ago. This current project seeks to improve the level of spatial detail by more accurately delineating smaller impervious features. Additionally, by using more recent source data this new layer will reflect development over the past 8-10 years.

1) Which Method and What Source Data?

These two elements, method and source data, are linked as one determines the other. This necessitated an inventory of available source data with a particular focus on currentness and spatial resolution. By knowing which data can be used, we can develop a list of project options. A summary of data is charted on Appendix 1 (Source Imagery Considered for Impervious Surface Project).

Land Cover – Land Use Data

Impervious surface estimations elsewhere have employed land use/cover classifications which are then assigned an impervious surface coefficient based upon previous study results. Total impervious surface can then be calculated by multiplying the individual landcover areas by the coefficients which are expressed as a percentage and then summing each cover type's impervious area. This method is employed in highly developed areas which have detailed municipal land use data; however, neither of these conditions exists in the Mat-Su basin making it susceptible to significant errors and therefore unsuitable for this project. Another reason for dismissing this approach is that the most recent and perhaps only comprehensive land cover dataset for the Mat-Su region is the USGS's National Land Cover Dataset of 2001 which is the baseline dataset for this project to measure change. The overall thematic accuracy of the Alaska NLCD was calculated to be 76% with lower values for less abundant landcover types. Due to the relative scarcity of the developed area classes (less than 0.1%) across the entire state, these land cover types were not considered by this study. (Selkowitz, Stehman, 2011).

Aerial Photograph or Natural Color Satellite Image Delineation

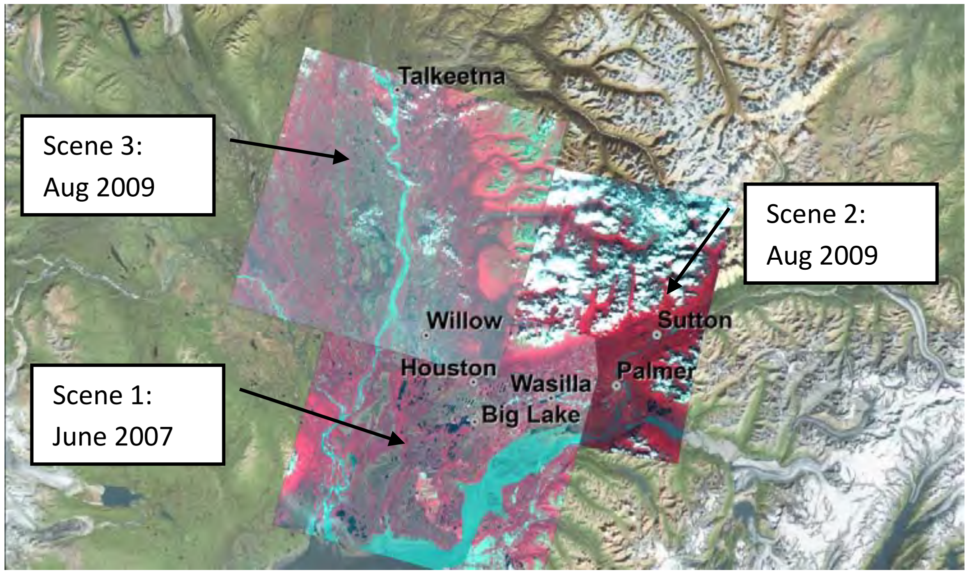
Other studies have utilized high resolution aerial photography to generate impervious surface layers. Manual plannimetric delineation methods were succeeded by computerized interpretation using a series of multiple training sites of known impervious surfaces to "train" the software to identify impervious areas. The Natural Resource Conservation Service (NRCS) of the US Department of Agriculture acquired orthrorectified color photography of much of the Mat-Su's developed lands in 2004-05. While these images offer excellent spatial resolution and an ability to finely demarcate smaller suburban features such as driveways and rooftops, the acquisition dates only provide an additional three to four years beyond the baseline dataset from 2001. The Nature Conservancy investigated purchasing commercial high resolution (0.5m-5m) imagery from the Quickbird, GeoEye, or RapidEye satellites. We were unable to find scenes that met our criteria of: cloud-free and snow-free images, sufficient spatial coverage, and within our project budget. Although we were unable to consider this methodology for the current study, the acquisition of high resolution orthophotography by the Mat-Su Borough during the summer of 2011 could lead to the development of a very fine scale impervious surface dataset in the future (Appendix 1:Source Imagery Considered for Impervious Surface Project).

NDVI – Normalized Difference Vegetation Index with Medium Resolution Satellite Data

The demand for remote sensing information has led to numerous satellites generating data of varying resolution and multiple bands. Much of these data are accessible via either commercial vendors or through academic research institutions. The University of Alaska's Alaska Satellite Facility (ASF) functions as a download and distribution center for the Japanese ALOS (Advanced Land Observation Satellite) data. The ALOS data are finer resolution than the baseline NLCD data (10meter vs. 30meter pixels) and offer four bands of information which permits standard remote sensing calculations such as the normalized difference vegetation index (NDVI). The NDVI is frequently referenced as a measure of greenness and is generated through the following equation where NIR = near infrared light wavelengths and VIS = visible light wavelengths.(NASA, 2011)

$$NDVI = (NIR-VIS)/ (NIR+VIS)$$

The NDVI value provides a simple and easily computed measure of vegetated landcover. Values can range from +1 (completely vegetated, vigorous growth) to -1 (devoid of vegetation). Pixels with negative NDVI values are interpreted as impervious surfaces. The ALOS data inventory includes relatively clear, summer scenes from the later part of the decade (2007, 2008, and 2009) which capture the more recent regional growth. The Alaska Satellite Facility's ability to acquire and process these scenes quickly and inexpensively met the final criteria for project data selection. The three ALOS scenes that were ultimately chosen and processed covered nearly 4,000,000 million acres, almost 16,000 square kilometers, or over 6,100 square miles. This area covers the entire Mat-Su core area of Palmer/Wasilla/Big Lake and runs north along the Parks Highway to Talkeetna.



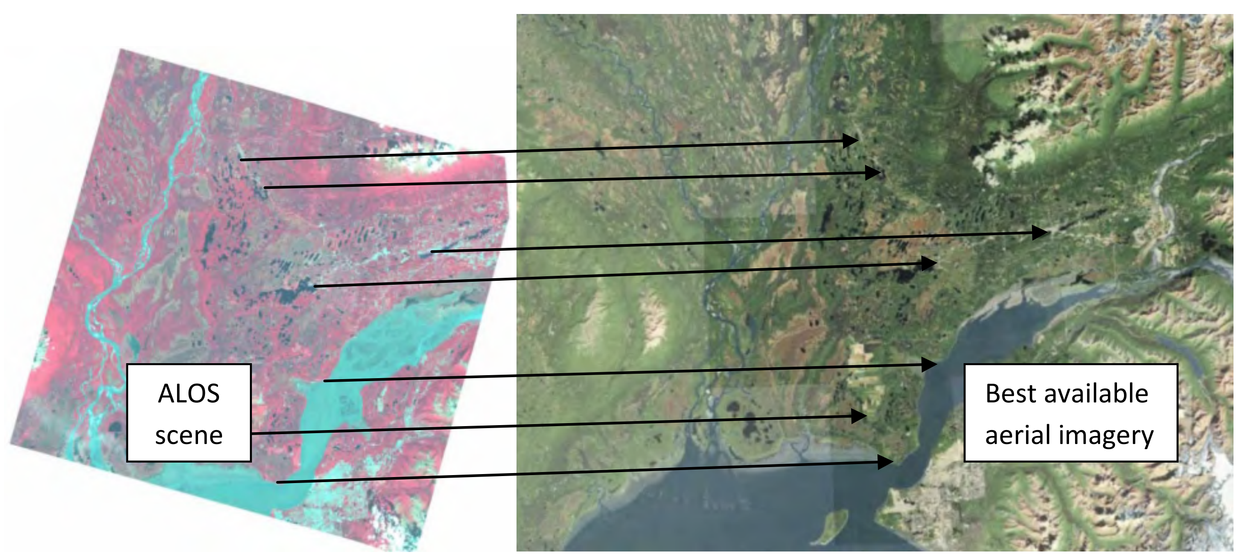
False color images of the ALOS scenes analyzed for this data layer. Note core developed areas and highway corridors are primarily clear and cloud free.

2) How to Process the Data:

This section will explain the basic processing steps used to generate the impervious surface through plain language and example graphics to illustrate the techniques as they were applied in this landscape. A more detailed accounting of the specific parameters and settings used for the data preparation can be found in the dataset's metadata available in multiple formats (html, pdf, xml)

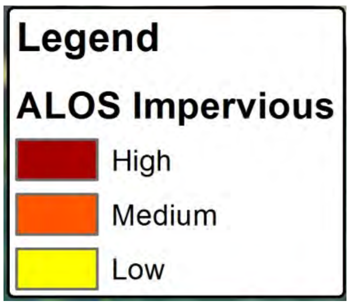
a) Georeferencing

Following the NDVI computation, the images were referenced to the best available aerial imagery for the area which was typically the 2004-2005 NRCS imagery. ASF staff used a rubbersheeting technique by selecting 70-90 control points on each ALOS image of easily identifiable locations (road intersections or lakes in remote areas) and then matched them to corresponding spots on the aerial photos.



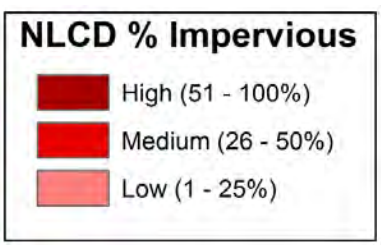
b) Converting NDVI to Impervious Surface Levels (high, medium, low thresholds)

The project's objective of comparing the more recent ALOS imagery to the 2001 NLCD imperviousness layer required a conversion from NDVI values ranging from +1 to -1 to values similar to the NLCD's percent impervious cover. Remote sensing experts at the Alaska Satellite Facility developed thresholds to delineate high, medium, and levels of impervious cover to facilitate analysis and comparison between watersheds and wit h the year 2001 impervious surface dataset. The exact threshold specifications for each ALOS satellite scene can be found in the final metadata file (impervious.html).



HIGH – large, contiguous areas of completely impervious surfaces: highways, expansive roofs and buildings, large parking lots, and heavily compacted lands within gravel pits

MEDIUM – most roads, moderately sized parking lots, and many residential and commercial structures



LOW – smaller roads including dirt and gravel roads, many smaller buildings and houses, some driveways

The coarse resolution of the NLCD imagery translates to pixels which are larger than most discrete impervious features that are to be measured in a rural/suburban environment (houses, small roads). On the ground this means that the NLCD pixels are often spanning areas that are not homogenous and therefore the pixel measures a percentage of impervious surface from 0-100%.

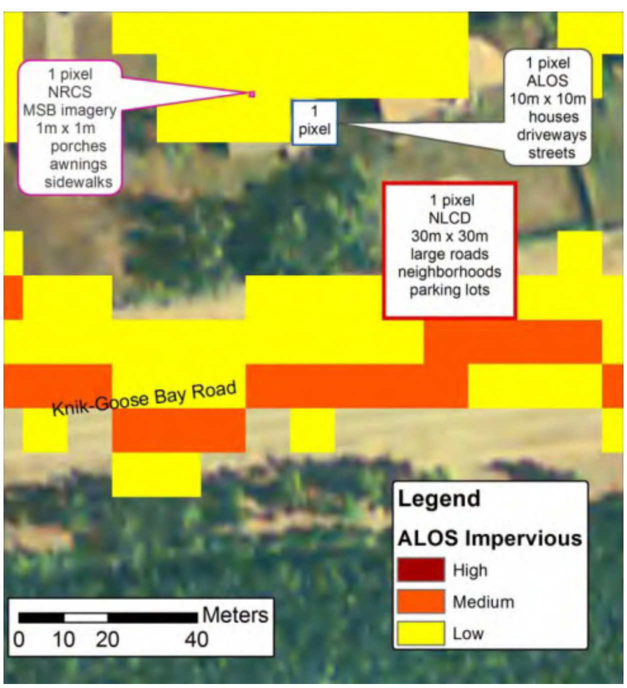
Example of various imagery sources' pixel sizes and how these varying dimensions represent different land cover types and their respective impervious surface levels

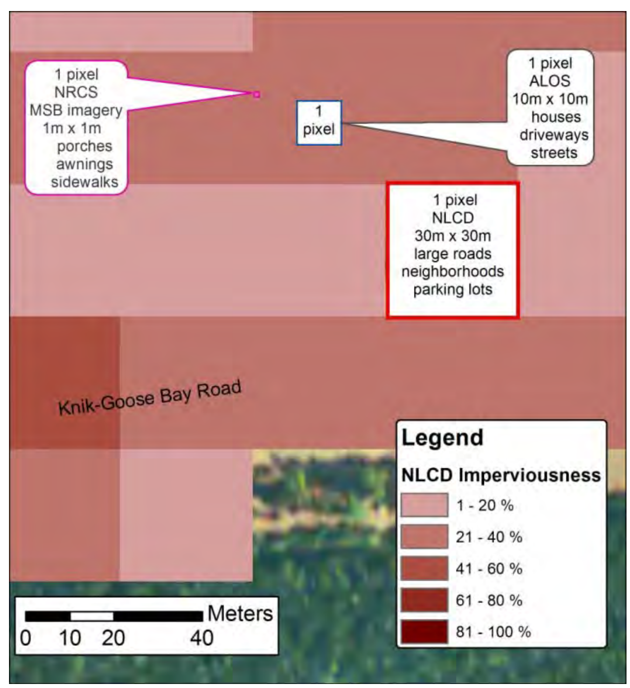
NLCD pixel = $900m^2$ or 0.22 acres

ALOS pixel = $100m^2$ or 1075 sq ft

(Below) The base NLCD pixels can only represent large features such as the road, most of the other pixels are a mix of impervious (houses) and vegetation (trees).

(Below) The ALOS pixel resolution delineates the road as well as the houses while not misclassifying the vegetation.

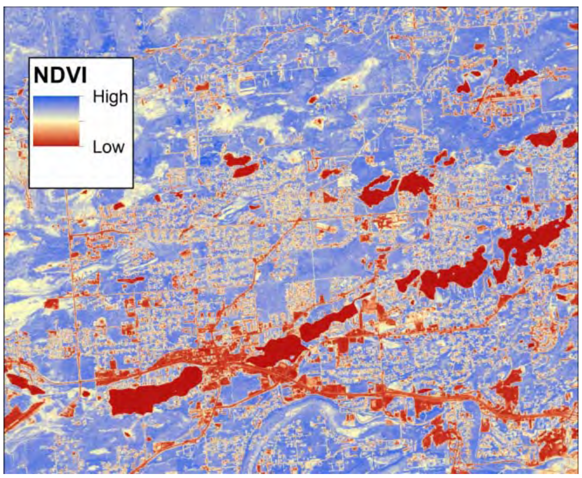




c) Roads

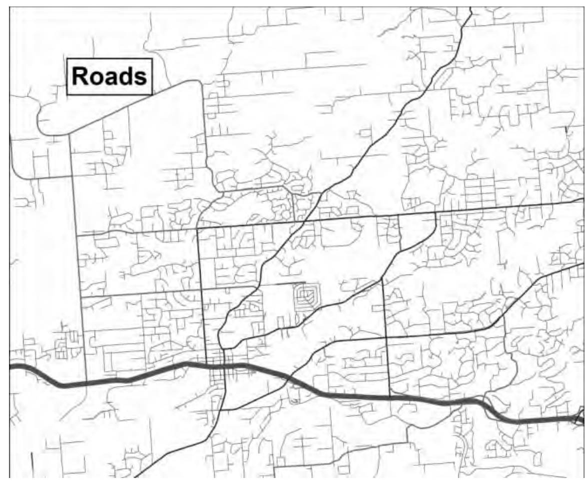
The unvegetated areas identified by the NDVI method required additional processing to develop a more accurate impervious surface layer to insure that known impervious surfaces were included. Numerous existing geographic information system (GIS) datasets were used to edit the raw NDVI. Alaska Satellite Facility staff converted the Matanuska-Susitna Borough's roads GIS layer into a raster layer and combined this data with the existing impervious layer to incorporate the roads. The current roads GIS layer does not include attributes such as road width or surface type (paved, gravel, dirt) so the roads raster layer was assigned a width of 10 meters and a moderate level of imperviousness. Future impervious surface datasets would benefit from such detailed road attributes.

Base NDVI



+

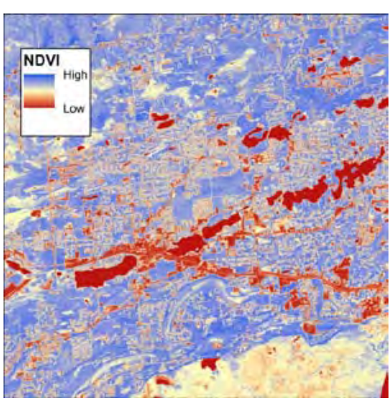
Vector Roads converted to 10m pixels



d) Water Mask

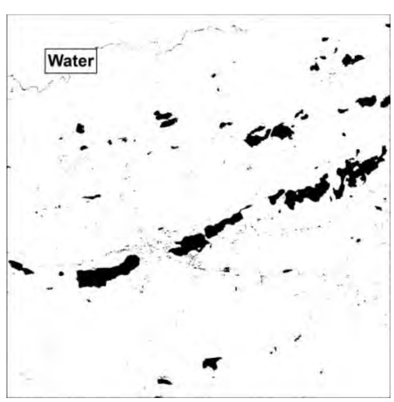
The NDVI calculation yields areas which are unvegetated yet it does not differentiate between human conversion and lands which are naturally devoid of vegetation. Using the ArcGIS Iso Cluster tool, ASF staff applied an initial water mask derived from the ALOS imagery to remove large water bodies from the impervious dataset. TNC staff then edited the data even further by converting the USGS' National Hydrographic Dataset of lakes and large rivers into a raster dataset to remove these areas.

NDVI



-

subtract ASF water mask



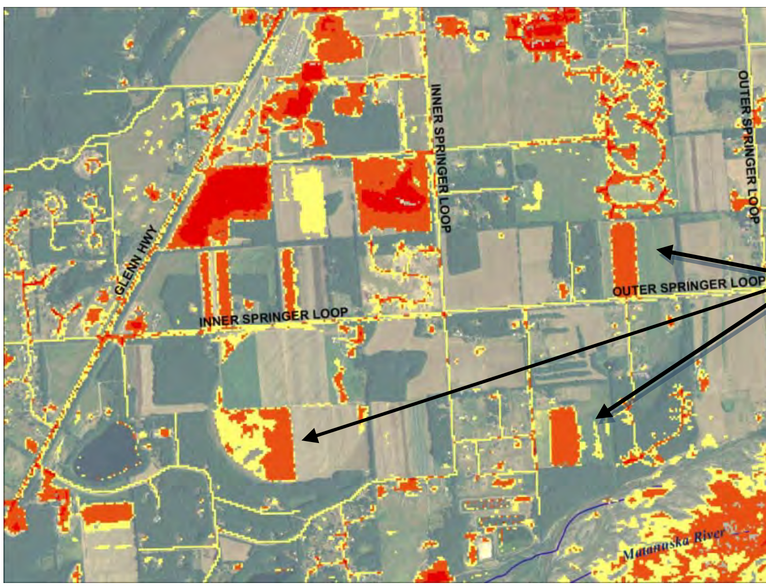
-

subtract TNC water mask

e) Manual Edits

TNC continued editing the data by manually removing pixels via onscreen editing at approximately 1:12,000 scale, using the most recent regional aerial photography for spot verification (NRCS, 2004, BING, 2010, ALOS – 2007-09). In cases where determining land cover (impervious or permeable) was difficult using the background imagery, Conservancy staff used Mat-Su Borough parcel level data to discern recent building construction activity (i.e. impervious surface development). The parcel data with taxable building values were selected and then symbolized to reflect the most recent construction which is not reflected in the 2004 NRCS imagery (Borough document date greater than 2004). Land uses with negative NDVI values that were most frequently removed from the impervious layers included: large gravel bars along major rivers, agricultural fields with differing NDVI values depending on cropping seasons, wetland complexes which had sufficient water content to decrease the NDVI, clouds, and lake shorelines and large rivers that extended beyond the NDVI and GIS derived water masks.

EXAMPLES (agricultural lands, gravel bars, and rivers)

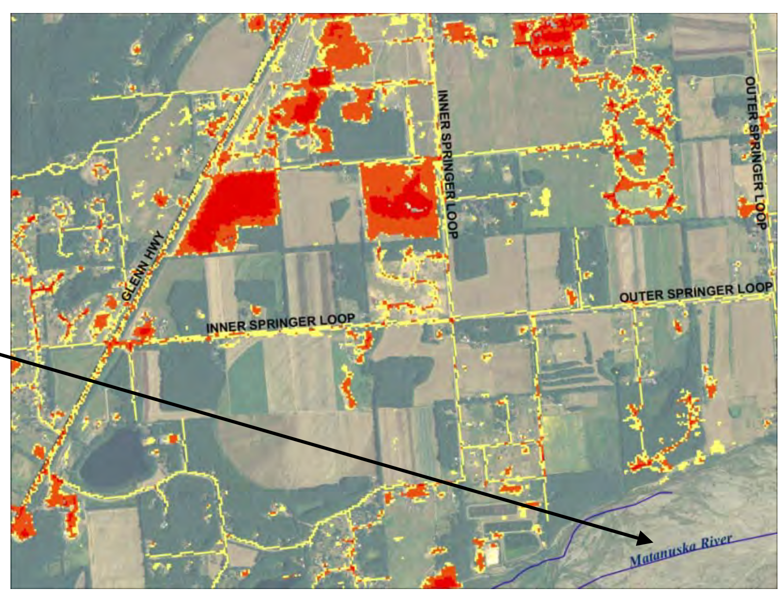


2004 NRCS imagery background with raw (unedited) impervious surface overlay – Glenn Highway, Palmer – State Fairgrounds area.

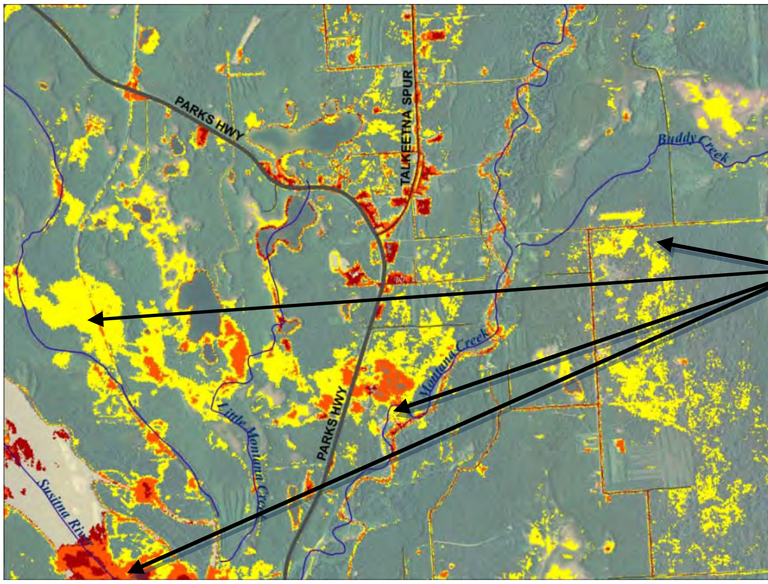
Agricultural lands miscoded in raw dataset, removed during editing

2004 NRCS imagery background with edited impervious surface overlay – Glenn Highway, Palmer State Fairgrounds area.

Matanuska River gravel bars removed from impervious dataset



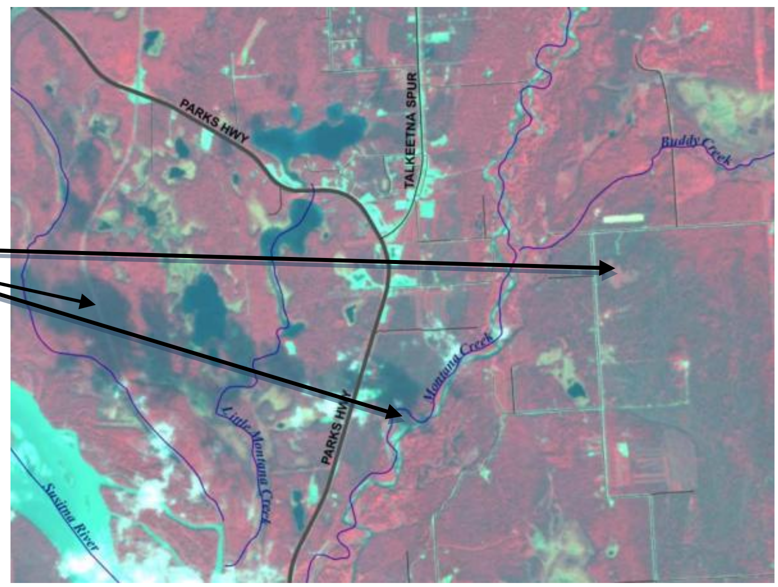
EDIT EXAMPLES continued (cloud removal, lakeshore edges)



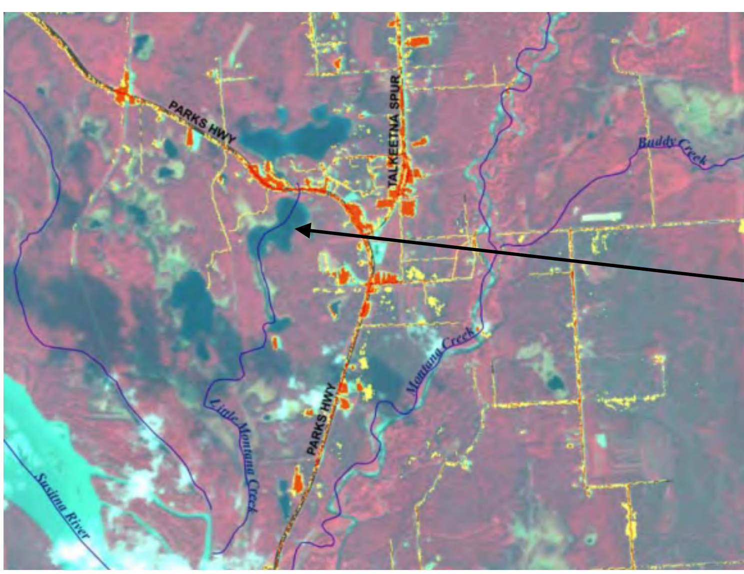
2004 NRCS imagery background with raw (unedited) impervious surface overlay – Parks Highway, Talkeetna "Y" area

Large impervious signal in region in a lightly developed area needs investigation

2009 ALOS false color imagery – Parks Highway, Talkeetna "Y" area.



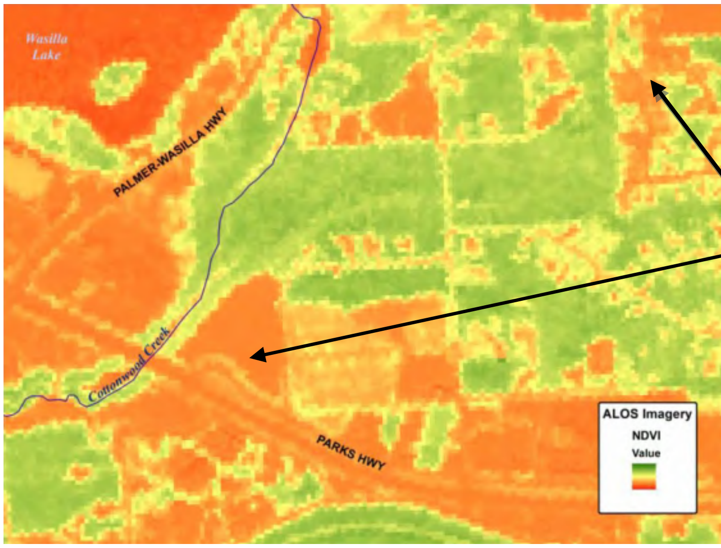
"Impervious signal" created by clouds and their shadows over the landscape



2009 ALOS false color imagery with final (edited) impervious surface dataset – Parks Highway, Talkeetna "Y" area.

Edits included removing clouds as well as this lakeshore rim effect created by misaligned water masks

EDIT EXAMPLES continued (verification with parcel data)

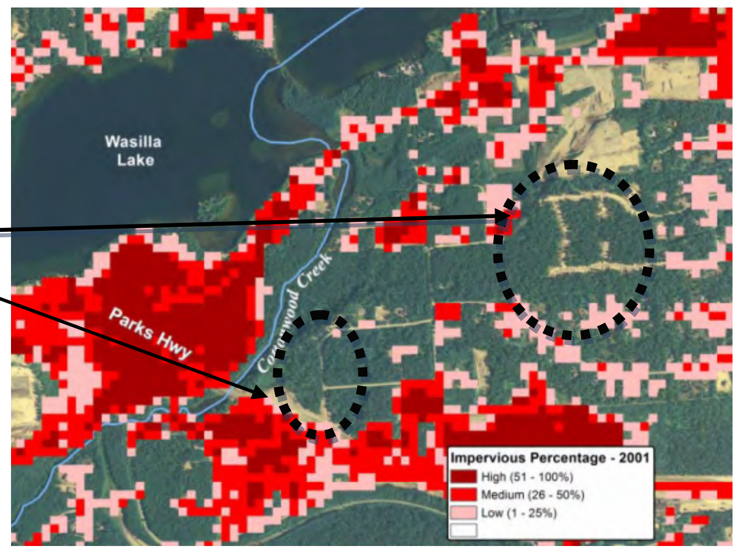


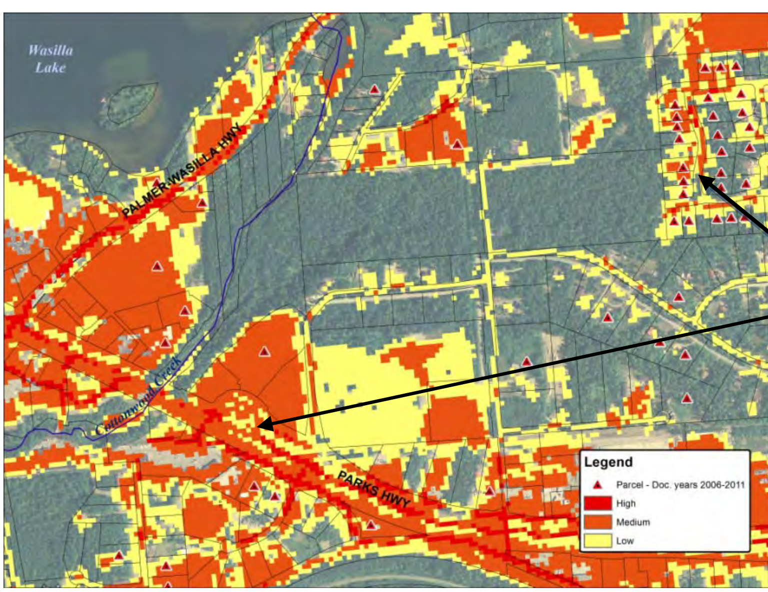
2007 ALOS NDVI imagery – Parks Highway, Cottonwood Creek area

Significant negative NDVI signal in areas not present in the 2001 NLCD data, warrants further investigation

2004 NRCS imagery with 2001 NLCD impervious surface data – Parks Highway, Cottonwood Creek area

Impervious surfaces not present in the 2001 NLCD, but with negative NDVI values shown

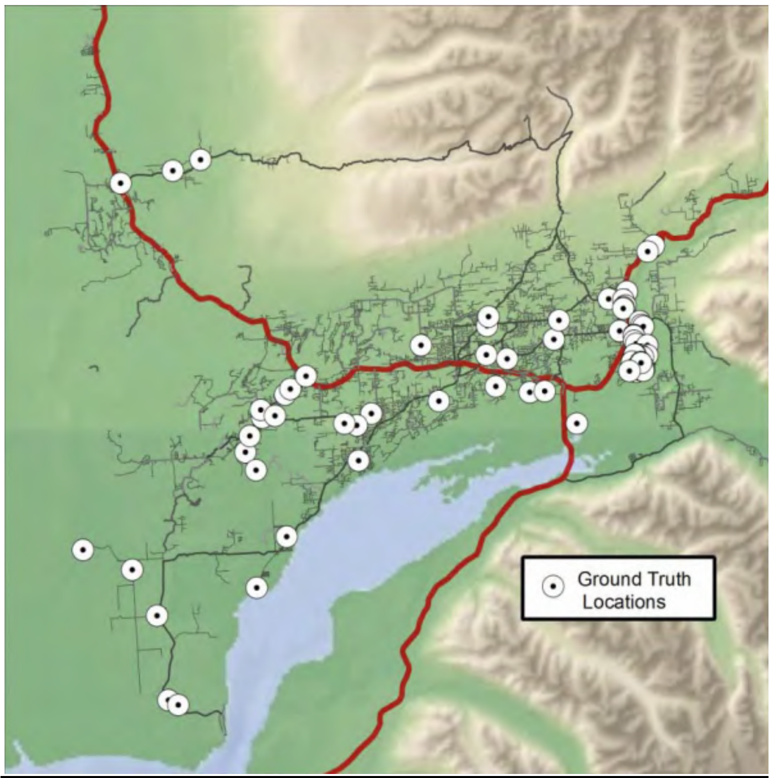




2004 NRCS imagery with TNC generated impervious surface dataset and MatSu Borough parcel data – Parks Highway, Cottonwood Creek area

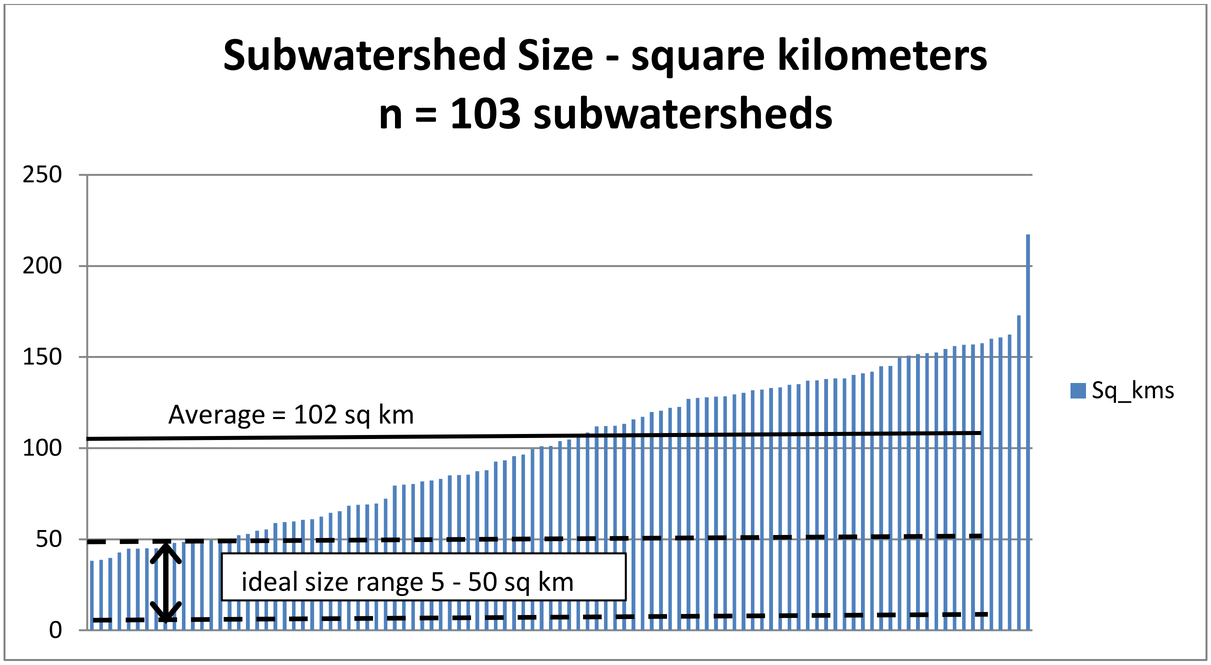
Red triangles represent parcels developed between 2006-2011 (MatSu Borough), confirming impervious growth as shown by NDVI *f) Ground truthing (field verification)*

Four separate field trips to the study region were conducted to visually verify actual land cover types across a wide range of settings. TNC staff selected ground truthing sites that captured locations where the NDVI derived impervious surface layer seemed to generate false positives (e.g. agricultural lands, riverine gravel bars, confirm cloud shadows, etc.). Additional sites included development in salmon watersheds of the Matanuska-Susitna core area.



ANALYSIS:

A recent meta-analysis of 65 impervious surface studies identified an ideal subwatershed size range of 5 to 50 square kilometers for accurately measuring impervious cover levels and their relative impact to water quality (Schueler, 2009). The three ALOS satellite scenes chosen for the study provided NDVI derived impervious values for 103 subwatersheds, also known as 12 digit hydrologic units, or HUC12s. They are defined by the US Department of Agriculture's Natural Resource Conservation Service Watershed Boundary Dataset (NRCS, 201). Although these subwatersheds are the finest resolution drainages available for the region, the average subwatershed size is 102 km^2 and over twice the recommended maximum area. These relatively large analysis areas can translate into relatively low measures of impervious surface coverage by diluting developed regions across larger landscapes. A further delineation of finer scale drainages in the future may be warranted to more accurately characterize more meaningful impervious surface measures.



Using the ArcGIS Tabulate Area command, the ALOS/NDVI impervious raster layer from years 2007 - 2009 was combined with the 103 subwatersheds yielding a tabular summary of impervious surface area by subwatershed (high, medium, and low square meters). These values were summed and divided by the watershed area to generate an overall percent impervious surface for each of the 103 subwatersheds.

Impervious Surface Percentage for year 2008 =

$$\frac{(\text{Low Impervious Area} * 0.75) + \text{Medium Impervious} + \text{High}}{\text{Subwatershed Area}}$$

Considering the 2001 impervious surface dataset's relatively coarse pixel size and its values of percent imperviousness ranging from 1 to 100%, a proportional method of calculating overall percent impervious by watershed was implemented. After using a similar tabulate area method in ArcGIS with the NLCD impervious raster layer and the subwatersheds, TNC staff weighted the areas for each increment of impervious surface by multiplying the area for each of the values by its inverse and then summing across all categories from 1% through 100%.

Impervious Surface Percentage for year 2001 (n=100) =

$$\frac{(\text{square meters of 1\% impervious} * (1/100)) + (m^2 \text{ of 2\% impervious} * (2/100)) + \ldots}{\text{Subwatershed Area}}$$

Impervious Growth Calculations:

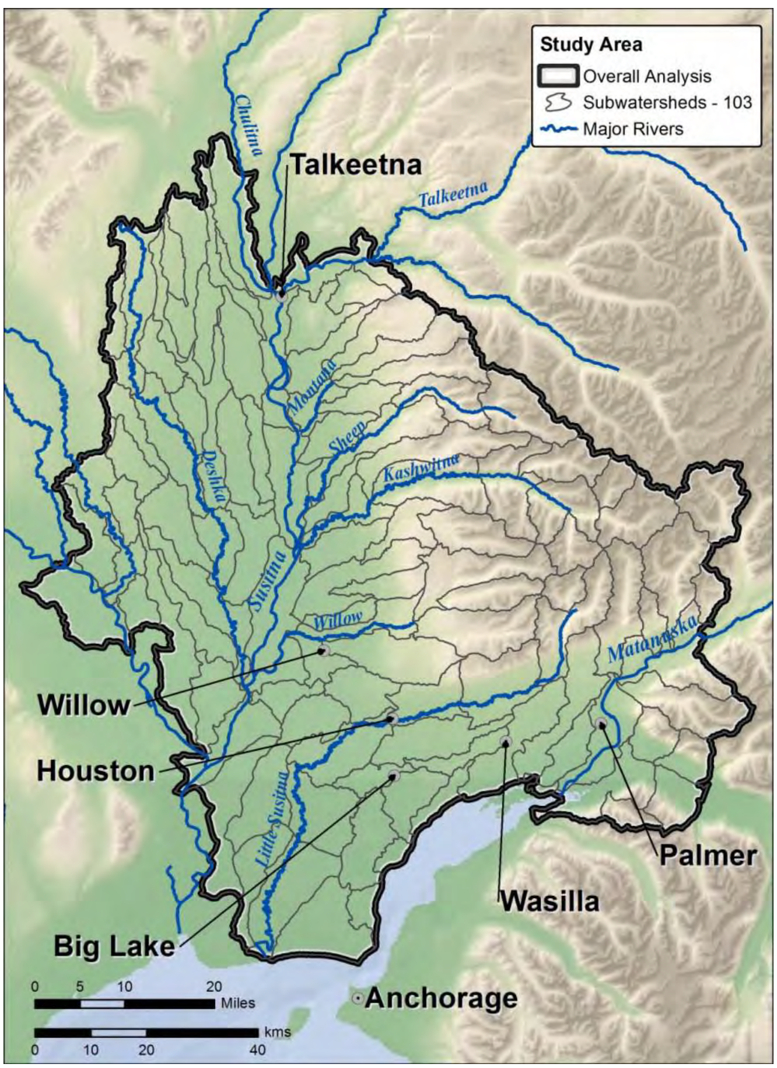
After computing values from the ALOS data and the NLCD data, the 2001 percentages were compared to the composite data from 2007-2009 to calculate impervious surface growth rates, both cumulative growth and an average annual growth rate over the approximately 7 years between source data.

$$\text{Cumulative Growth} = \frac{\text{2008(ALOS) Impervious Area} - \text{2001 (NLCD) Impervious Area}}{\text{2001 (NLCD) Impervious Area}}$$

$$\text{Annual Growth Rate} = \frac{\text{Cumulative Growth}}{\text{7 (years)}}$$

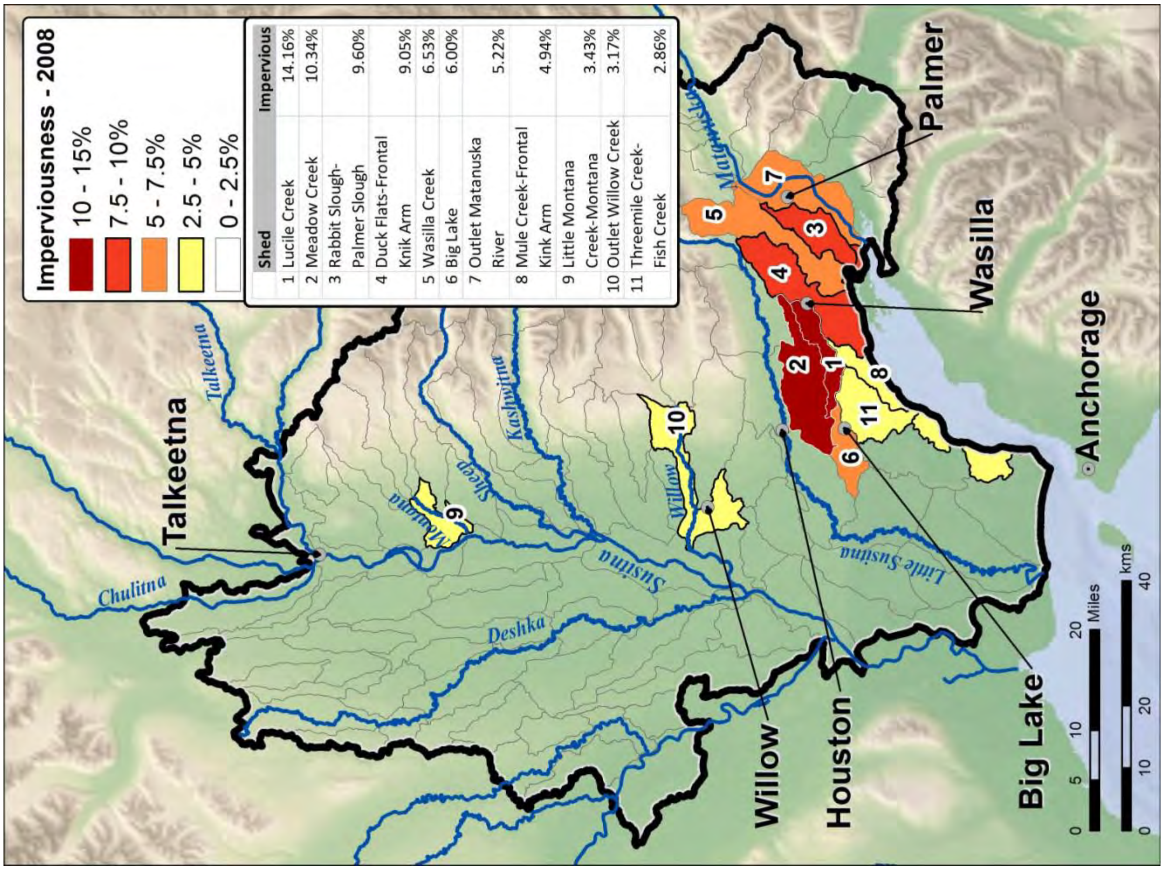
RESULTS:

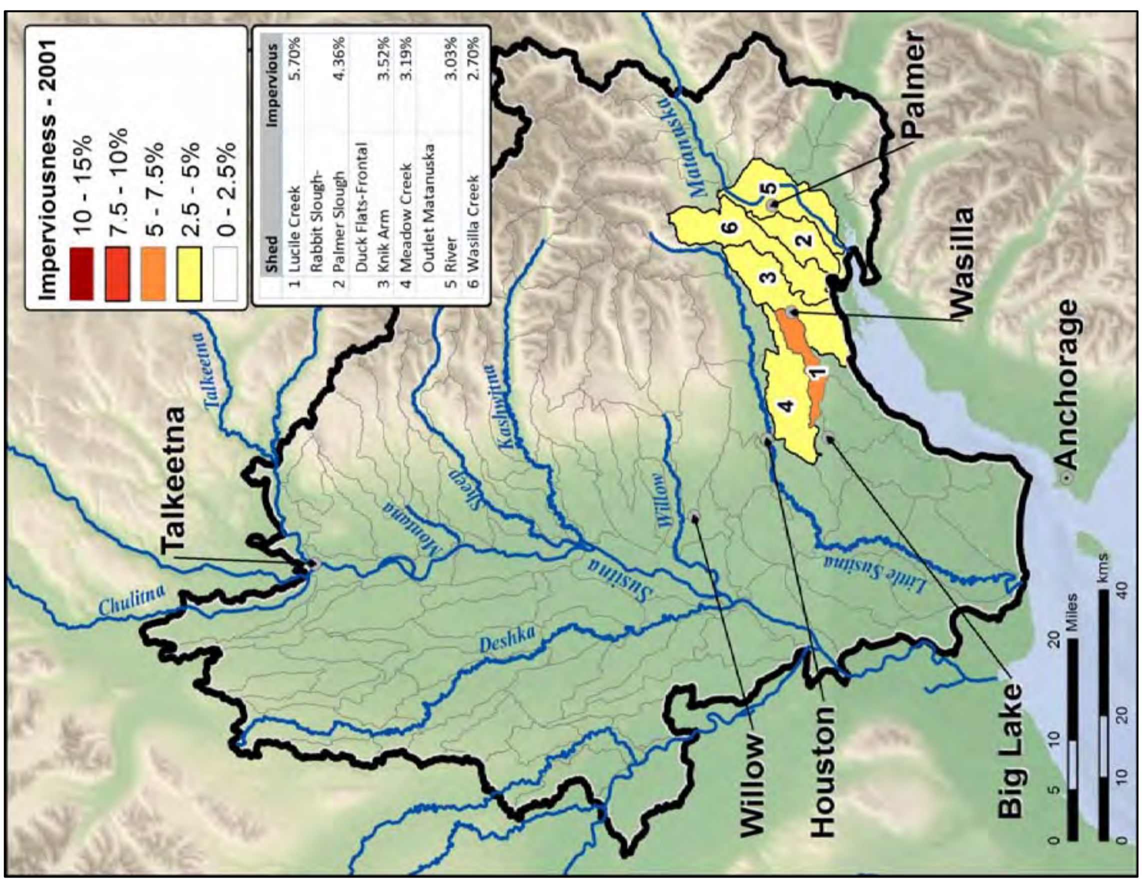
The study's results can be viewed as tables, as maps summarized by watershed, or in GIS formats suitable for numerous mapping software. Impervious cover values from the baseline, year 2001, NLCD derived dataset ranged from 5.7% (Lucile Creek subwatershed) to 0% (numerous subwatersheds). The updated ALOS generated impervious surface values ranged from a high 14.16% (Lucile Creek) to 0%. The subwatersheds with the highest impervious surface values can be found on the maps shown on the following page.



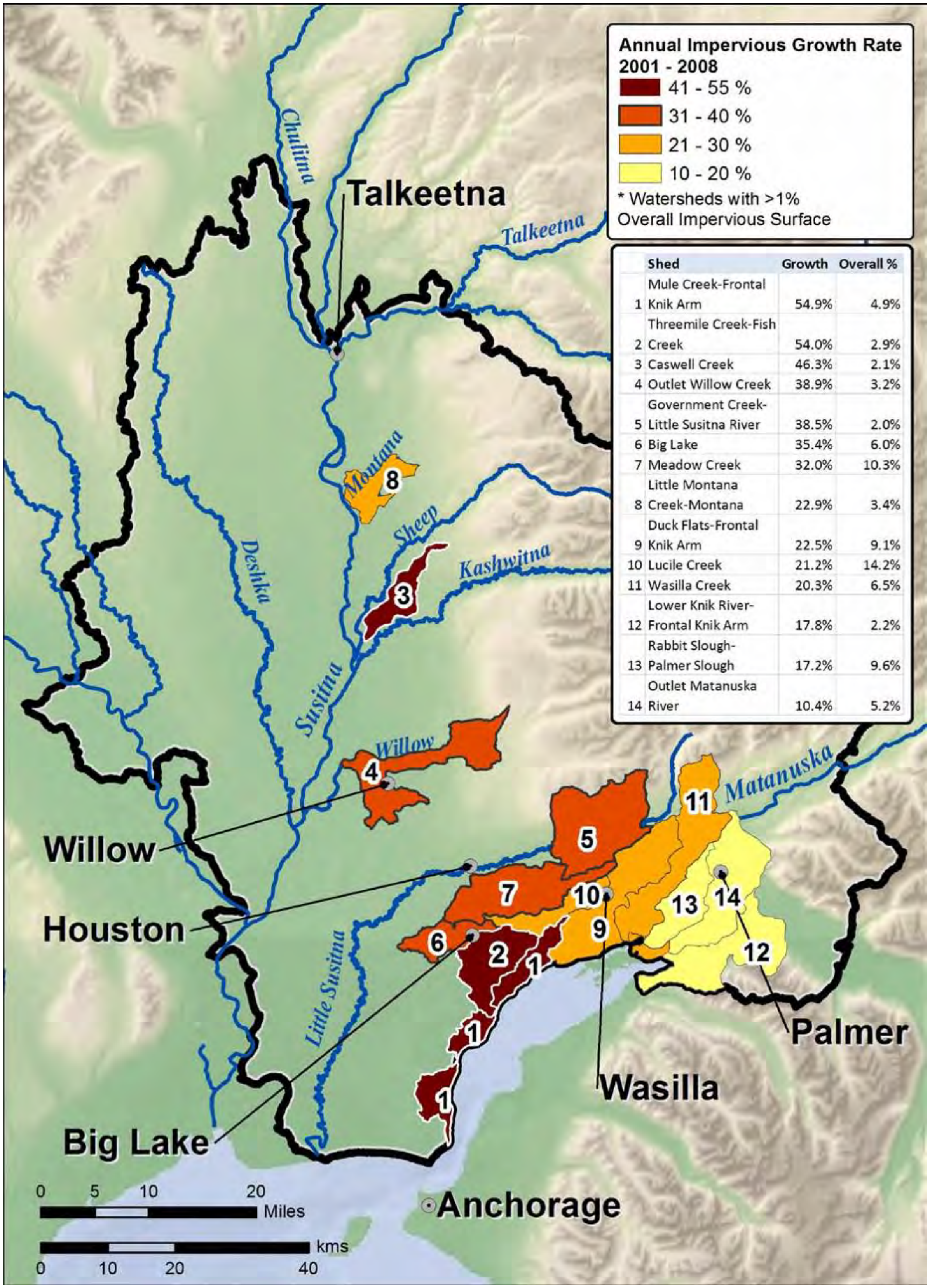
Study area encompasses 10,500 square kilometers, or 4048 square miles and includes the Mat-Su's core developed area stretching from Palmer west through Wasilla and Big Lake and then following the Parks Highway corridor north to Talkeetna.

Impervious Surface Percentages by Subwatershed: 2001 and 2008





Watersheds with fastest impervious surface growth over the past seven years.



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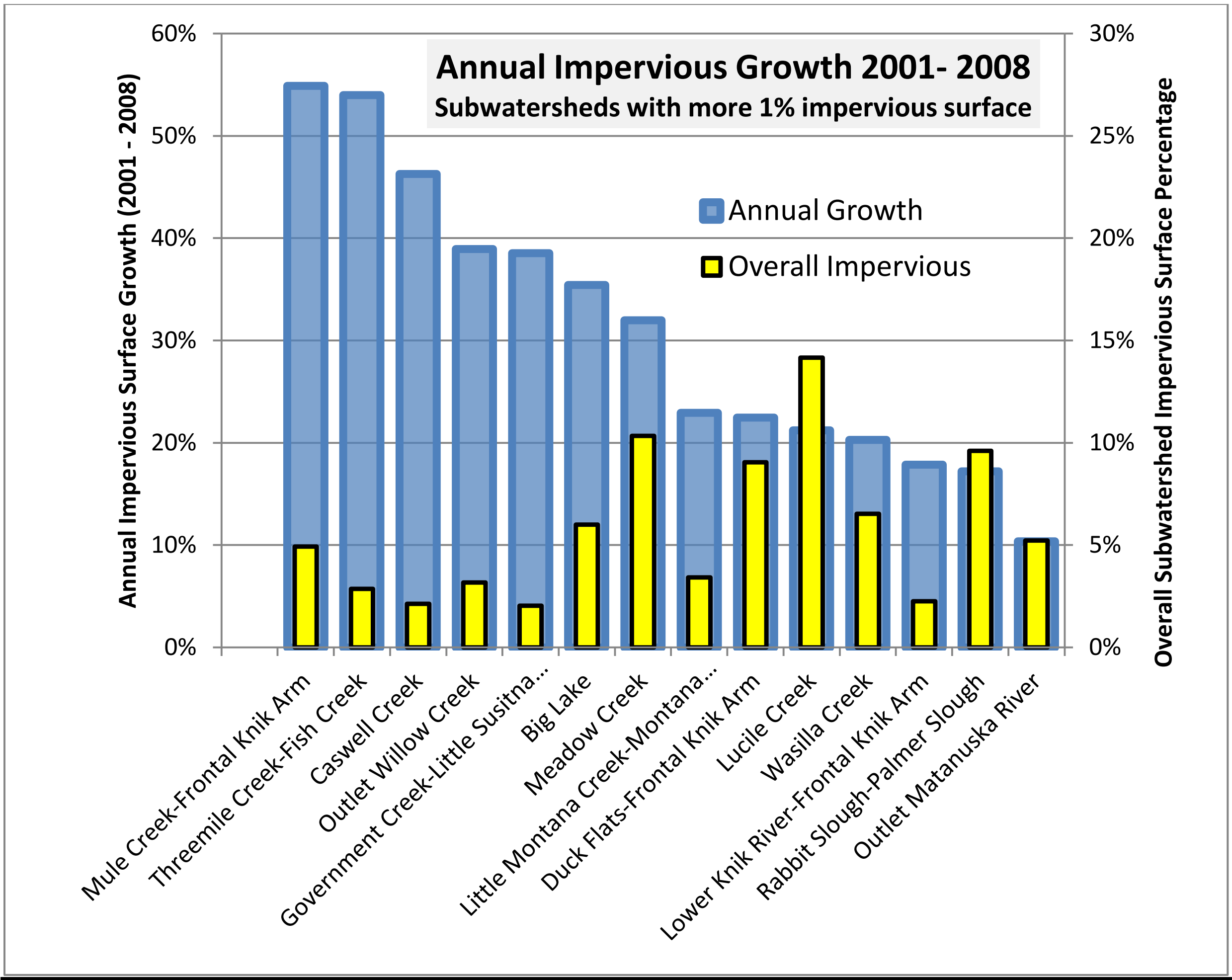


DISCUSSION AND RECOMMENDATIONS:

- Future work should focus on most developed and fastest growing regions
- Use LiDAR data to delineate finer scale drainages
  - The higher resolution digital elevation data would permit creation of detailed drainage networks and watersheds
- Examine hydrologic connectivity of impervious surfaces to salmon streams
  - Inventory regional stormwater management systems, map areas implementing best management practices such as rain gardens and vegetated drains.
- 2011 aerial imagery to study impervious growth in sensitive riparian areas
  - Create a fine scale (one meter) impervious layer within important habitat such as a riparian buffer along streams.

ACKNOWLEDGEMENTS:

This dataset was created with financial support from the US Fish and Wildlife Service's Coastal Program in the Anchorage (Alaska) Field Office, Wallace Research Foundation, and Conoco Phillips Alaska, Inc. and through a partnership with Dr. Don Atwood and Moritz Wurth at the Alaska Satellite Facility at the University of Alaska Fairbanks.

Works Cited

Mat-Su Salmon Partnership. 2008. Conserving Salmon in the Mat-Su Basin: The Strategic Action Plan of the Mat-Su Basin Salmon Habitat Partnership. The Nature Conservancy: Anchorage, Alaska.

NASA, 2011. Measuring Vegetation (NDVI & EVI). National Aeronautics and Space Administration, http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php

NRCS, 2001. Watershed Boundary Datatset. , http://datagateway.nrcs.usda.gov/

Schueler, R., Fraley-McNeal, L., Cappiella, K. (2009). Is Impervious Cover Still Important? Review of Recent Research. *Journal of Hydrologic Engineering* , 309-315.

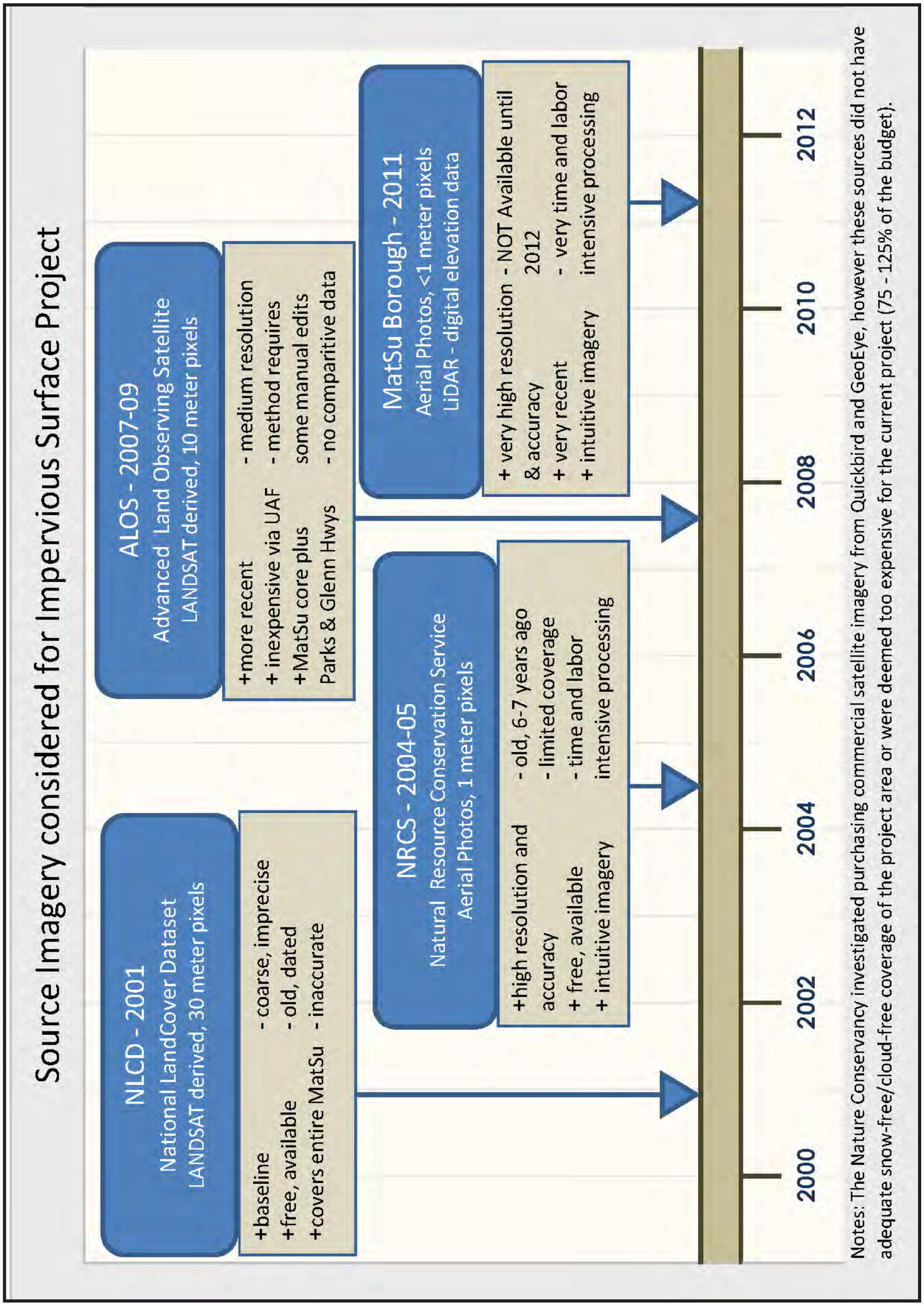
Schueler, R., Fraley-McNeal, L. (2008). The Impervious Cover Model Revisited: review of recent ICM research. Symposium on Urbanization and Stream Ecology, May 2008. Salt Lake City, Utah.

Selkowitz, D., Stehman, S. (2011). Thematic accuracy of the National Land Cover Database (NLCD) 2001 land cover for Alaska. *Remote Sensing of Environment,* 115, 1401-1407.

US Census Bureau (2011), http://quickfacts.census.gov/qfd/states/02/02170.html

USGS (2008), National Land Cover Dataset. Percent Developed Impervious Zone 8. http://www.mrlc.gov/nlcd01_data.php

APPENDIX 1: Source Imagery considered for Impervious Surface Project



Effects of Urbanization on Benthic Macroinvertebrate Communities in Streams, Anchorage, Alaska

Water-Resources Investigations Report 01–4278

Oblique aerial view of downtown Anchorage and Cook Inlet, Alaska (photograph taken in 2001 by author)

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Effects of Urbanization on Benthic Macroinvertebrate Communities in Streams, Anchorage, Alaska

By Robert T. Ourso

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01–4278

Anchorage, Alaska
2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

For additional information, contact:

District Chief
U.S. Geological Survey
4230 University Drive, Suite 201
Anchorage, AK 99508–4664

URL: <http://ak.water.usgs.gov>

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life and facilitates effective management of water, biological, energy, and mineral resources. (URL: <http://www.usgs.gov/>). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

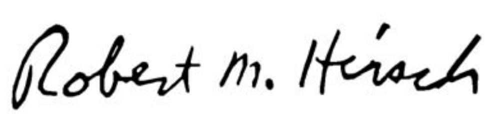
The USGS implemented the National Water-Quality Assessment (NAWQA) program to support national, regional, and local information needs and decisions related to water-quality management and policy. (URL: <http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resources management and strategies that protect and restore water quality.

Since 1991, the NAWQA program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as study units. (URL: <http://water.usgs.gov/nawqa/nawqamap.html>). Collectively, these study units account for more than 60 percent of the overall water use and population served by public water supply and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multiscale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the study-unit findings. (URL: <http://water.usgs.gov/nawqa/natsyn.html>).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA program recognizes that a national assessment by a single program cannot address all water-resources issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, nongovernment organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, WATER-QUALITY AND OTHER METRIC UNITS, and VERTICAL DATUM

Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
mile per square mile (mi/mi^2)	0.6212	kilometer per square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

In this report, water temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the equation

$$°F = 1.8\ (°C) + 32$$

and ambient (air) temperature is reported in degrees Fahrenheit(°F), which can be converted to degrees Celsius (°C) by the equation

$$°C = (°F - 32) / 1.8$$

Abbreviated water-quality and other metric units used in this report: Chemical concentration in water, or solute mass per unit volume (liter) of water, is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). (A concentration of 1,000 µg/L is equivalent to a concentration of 1 mg/L. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.) Specific conductance is given in microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Other metric units used are micron (µm), centimeter (cm), and square meter (m^2). The unit used for algal standing crop is milligram per square meter (mg/m^2). Standard units are used for pH.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called "Sea-Level Datum of 1929"), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Effects of Urbanization on Benthic Macroinvertebrate Communities in Streams, Anchorage, Alaska

By Robert T. Ourso

Abstract

The effect of urbanization on stream macroinvertebrate communities was examined by using data gathered during a 1999 reconnaissance of 14 sites in the Municipality of Anchorage, Alaska. Data collected included macroinvertebrate abundance, water chemistry, and trace elements in bed sediments. Macroinvertebrate relative-abundance data were edited and used in metric and index calculations. Population density was used as a surrogate for urbanization. Cluster analysis (unweighted-paired-grouping method) using arithmetic means of macroinvertebrate presence–absence data showed a well-defined separation between urbanized and nonurbanized sites as well as extracted sites that did not cleanly fall into either category. Water quality in Anchorage generally declined with increasing urbanization (population density). Of 59 variables examined, 31 correlated with urbanization. Local regression analysis extracted 11 variables that showed a significant impairment threshold response and 6 that showed a significant linear response. Significant biological variables for determining the impairment threshold in this study were the Margalef diversity index, Ephemeroptera–Plecoptera–Trichoptera taxa richness, and total taxa richness. Significant thresholds were observed in the water-chemistry variables conductivity, dissolved organic carbon, potassium, and total dissolved solids. Significant thresholds in trace elements in bed sediments included arsenic, iron, manganese, and lead. Results suggest that sites in Anchorage that have ratios of population density to road density greater than 70, storm-drain densities greater than 0.45 miles per square mile, road densities greater than 4 miles per square mile, or population densities greater than 125–150 persons per square mile may require further monitoring to determine if the stream has become impaired. This population density is far less than the 1,000 persons per square mile used by the U.S. Census Bureau to define an urban area.

INTRODUCTION

The U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) program began studies in the Cook Inlet Basin (COOK) study unit in 1997. The goal of the COOK study is to describe the status and trends in the quality of water in the basin and to relate that to an understanding of the natural and human factors controlling water quality.

Increasing urban populations, and the urban sprawl associated with the increase in population, are known to alter drainage basins and the streams that drain these urbanized catchments. Point sources of pollution in the U.S. and most developed countries have been studied intensely and regulated more closely since the passage of the Clean Water Act. The understanding of point-source pollution and its effects has shown that other factors contribute to the degradation of urban water quality as streams still show impairment. Many prior studies describe the effects of nonpoint-source pollution on water quality, especially in urban areas (Klein, 1979; Milner and Oswood, 1989; Wear and others, 1998; Winter and Duthie, 1998). Nonpoint-source pollution factors that are commonly cited as detrimental to water quality are increases in conductivity due to road deicing, organic pollution from high-density livestock facilities, nutrient enrichment from fertilizers, and petroleum byproducts from the use of vehicles, among many others.

Associated with increases in population is increased impervious area, which leads to elevated runoff and streamflows over short time periods. As water in the catchment exits the system more rapidly owing to increases in impervious cover, low flows tend to decrease, and the overall habitat availability for stream-dwelling organisms correspondingly decreases. Increases in pollutants, which also are attributed to increasing populations and impervious areas, exacerbate the problems associated with lowered discharges: Because less water is available for dilution of pollutants, resident organisms are subjected to increasing stress. Macroinvertebrate-community structures have shifted from greater numbers of specialist feeders in undisturbed areas to greater numbers of generalists in less-diverse disturbed areas (Whiting and Clifford, 1983; Garie and McIntosh, 1986).

Anchorage presents a unique opportunity to study the effects of urbanization on benthic macroinvertebrates. Streams in Anchorage originate in undisturbed catchments and then course through areas having different population densities before emptying into Cook Inlet. This report generally describes the results of site reconnaissance for a study examining the changes in water quality along an urban gradient and specifically examines the response of benthic macroinvertebrates to changes in water quality along a gradient of urbanization in five stream basins within the Municipality of Anchorage, Alaska.

BASIN CHARACTERIZATION

The hydrology of Anchorage is dominated by five stream basins, all having headwaters in the Chugach Mountains, which border the municipality on the east side. Each stream courses through the city on the way to its mouth along the Cook Inlet. Anchorage, the most populated city in the State, is located within the Cook Inlet Basin in south-central Alaska. More than one-third of Alaska's population lives in Anchorage. Estimated population of the municipality as of 1996 was approximately 254,000 (Municipality of Anchorage, 1996). The mean annual precipitation is 20 to 25 in. and average temperature is about 27°F (Brabets and others, 1999).

Streams are affected by ice cover for a significant part of the year. Ice typically forms over the streams in late November to early December and open water reappears around the beginning of April. The time of ice cover varies according to the elevation of a particular segment of the stream.

The geology consists primarily of unconsolidated Quaternary alluvial or glacial deposits in the lower elevations and Mesozoic metamorphic, volcanic, and igneous rock in the Chugach Mountains on the east side (Brabets and others, 1999).

Land cover is dominated by moist herbaceous and shrub tundra. Open and closed spruce forest, low and tall shrub, and alpine tundra and barrens cover smaller areas (Brabets and others, 1999). Within the area under investigation in this study, land use is principally forest (military lands and State parklands) and urban (residential and commercial).

STUDY SITES

The five stream basins within the Municipality of Anchorage (**fig. 1**, **fig. 2**, **table 1**) that were chosen for the study were, from north to south, Ship Creek, Chester Creek, Campbell Creek, Rabbit Creek, and Little Rabbit Creek. During August–September 1999, 14 stream sites (**appendix 1**) were selected to represent these 5 basins—2 sites in the Ship Creek Basin and 3 in each of the other 4 basins. Total basin areas range from 125 mi^2 (Ship Creek) to 6.4 mi^2 (Little Rabbit Creek). Snowmelt from the Chugach Mountains is the primary contributor to surface-water flow within the five basins studied.

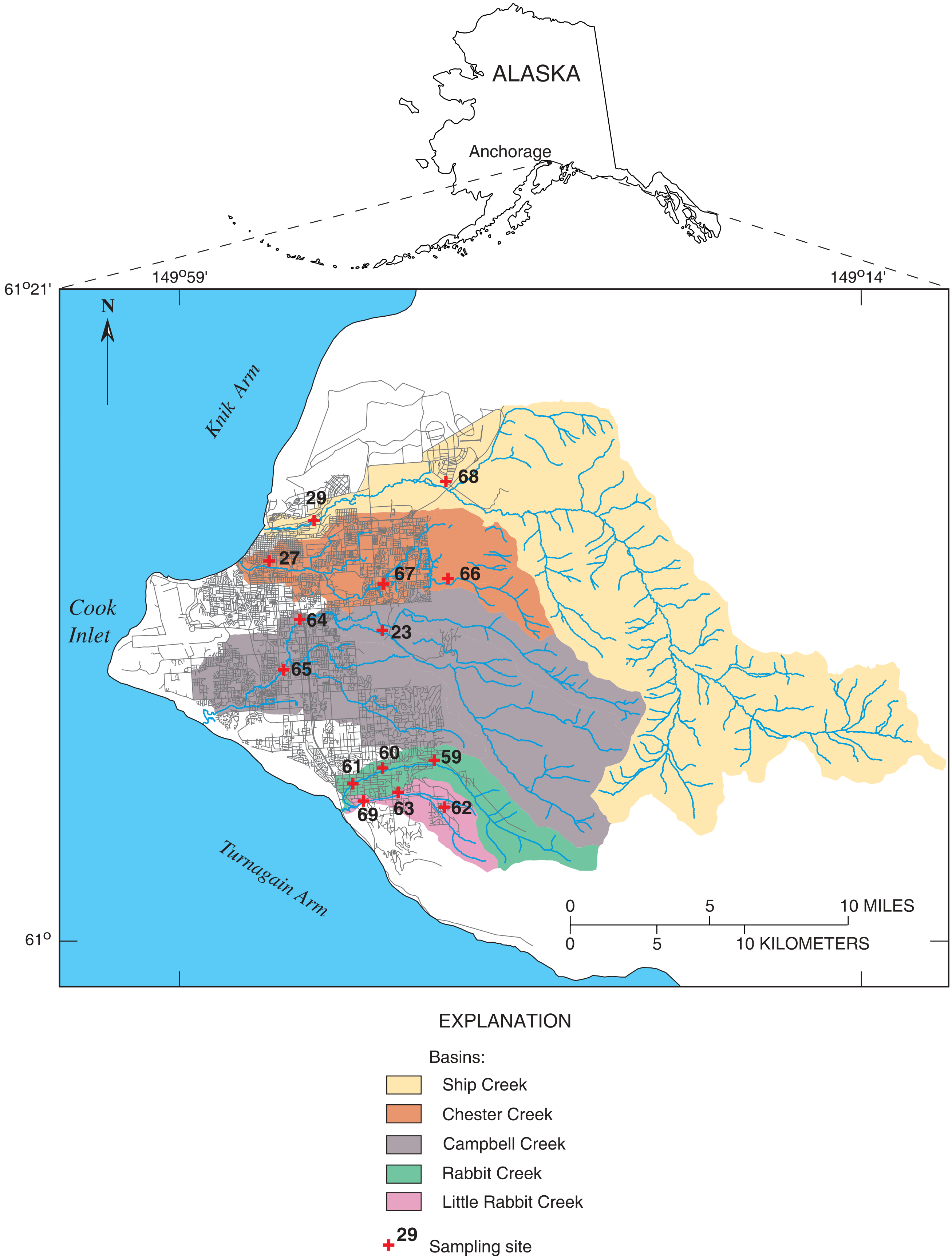

Figure 1. Anchorage area, showing stream basins and sampling sites. Site numbers (appendix 1) correspond to those introduced by Brabets and others (1999) in their National Water-Quality Assessment environmental-setting study.

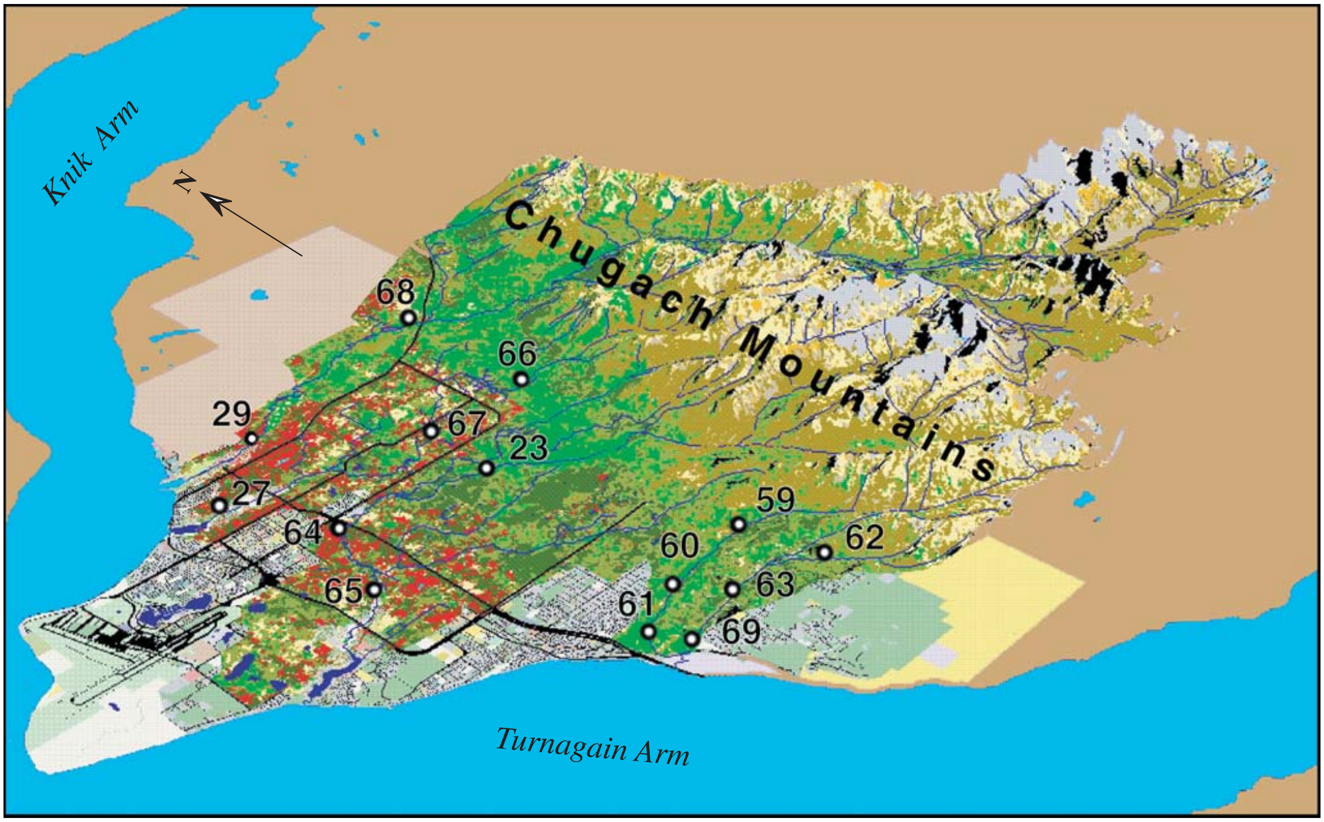

Figure 2. Three-dimensional representation of Anchorage area and sampling sites. (See fig. 1 and appendix 1 regarding sampling sites.)

Sites initially were selected on the basis of their position along a gradient of urbanization as represented by road density (miles of road per square mile of drainage area) upstream from each sample site. The South Fork of Campbell Creek (site 23, fig. 1) and Chester Creek at Arctic Boulevard (site 27) were gaged sites and were planned as upper and lower (respectively) endpoints of the gradient. Upstream sites were chosen on the basis of level of development and access. Upstream sites had road densities that ranged from 0 to 2.1 mi/mi^2 (table 1). Intermediately positioned sites had a greater degree of development (road-density range, 0.9 to 4.2 mi/mi^2). The farthest downstream sites were the most highly developed sites within their respective basins and had road densities ranging from 0.57 to 9.2 mi/mi^2. Ship Creek skewed the road-density calculations at its upstream and downstream sites owing to the overall size of the contributing area of the basin upstream from each site. The most current land-use and population information, used to calculate urbanization metrics, was assembled from land-use maps, satellite images, aerial photography, and geographic information systems databases.

Table 1. Description of sites

[Site no.: Number used in this report (see figs. 1 and 2 for site locations); corresponds to site number assigned by Brabets and others (1999) in earlier National Water-Quality Assessment report. Sites are ordered from least to greatest population density]

Site no.	U.S. Geological Survey station: Station number	U.S. Geological Survey station: Name	Elevation (feet above sea level)	Upstream watershed area (square miles)	Discharge (cubic feet per second)	Specific conductance (microsiemens per centimeter at 25°C)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Road density (miles per square mile)	Population density (persons per square mile)	Storm-drain density (miles of storm sewers per square mile)	Ratio of population density to road density
66	15274796	South Branch of South Fork Chester Creek at Tank Trail	358	4.3	3.4	113	8.2	4.5	11.4	0	0	0	0
68	15276200	Ship Creek at Glenn Highway	286	103.4	148	156	7.5	7	11.8	.1	0	.00	0
23	15274000	South Fork Campbell Creek	233	29.2	58	72	7.7	4	12.7	.33	9	0	29.42
29	15276570	Ship Creek below powerplant at Elmendorf Air Force Base	47	113.3	224	169	7.6	9.5	10.7	.6	28	.08	48.28
59	15273020	Rabbit Creek at Hillside Drive	876	9.8	30	86	7.3	3.5	12.2	.98	32	0	32.68
62	15273090	Little Rabbit Creek at Nickleen Street	1,230	2.6	6.2	109	7.7	1	12.6	2.12	60	0	28.36
63	15273097	Little Rabbit Creek at Goldenview Drive	590	5.6	15	128	7.9	2.5	12.8	4.2	125	0	29.86
60	15273030	Rabbit Creek at East 140th Avenue	436	11.3	28	90	7.6	6	12.5	2.97	136	0	45.92
64	15274395	Campbell Creek at New Seward Highway	98	45.9	78	84	7.6	5	11.6	.89	176	.45	198.48
69	15273100	Little Rabbit Creek	92	6.4	15	137	7.9	3	12.4	4.77	182	0	38.39
61	15273040	Rabbit Creek at Porcupine Trail	121	13.3	34	96	7.6	6	12.2	4.04	262	0	64.93
65	15274557	Campbell Creek at C Street	52	65.7	89	92	7.9	8	8.9	3.55	662	1.59	186.52
67	15274830	South Branch of South Fork Chester Creek at Boniface Parkway	197	14.8	12	168	7.7	8	11.7	4.14	1,222	3.22	295.1
27	15275100	Chester Creek at Arctic Boulevard	16	27.3	31	242	8.1	11.5	10.4	9.24	2,736	6.95	296.2

FIELD METHODS

Water-chemistry data (major ions, nutrients, dissolved and suspended organic carbon), field properties (stream discharge, specific conductance, dissolved oxygen, pH, and water temperature), concentrations of trace elements in streambed sediments, macroinvertebrate relative abundances, and chlorophyll-*a* data were collected to assess water quality along the urban gradient. For most sites, data were collected during August 23 to September 23, 1999; for the South Fork of Campbell Creek (site 23), data collected in late July 1999 as part of the NAWQA basic fixed-site sampling regime was used.

Water samples for major ions and nutrients and streambed-sediment samples for trace elements were collected according to NAWQA protocols (Shelton, 1994; Shelton and Capel, 1994) and sent to the USGS National Water-Quality Laboratory (NWQL) for constituent analysis. Major ions and trace elements addressed in this report include calcium, magnesium, sodium, potassium, sulfate, chloride, phosphorus, iron, manganese, aluminum, arsenic, cadmium, cobalt, copper, chromium, lead, mercury, molybdenum, nickel, selenium, silver, sulfur, and zinc.

Epilithic periphyton (algae attached to rocks) was collected using quantitative methods described by Porter and others (1993) and fluorometrically analyzed for chlorophyll-*a* concentrations at the University of Alaska at Fairbanks. Three algae samples comprising five rocks each were collected in each reach. These concentrations were averaged to measure algal standing crop in milligrams per square meter.

Macroinvertebrate samples were collected according to NAWQA protocols (Cuffney and others, 1993). The richest targeted habitat (RTH or semiquantitative) method was designed to provide identification and enumeration of species within a given area. Riffles, which are known to support a taxonomically rich macroinvertebrate community (Hynes, 1970), were targeted for semiquantitative sampling. Five samples, each representing a sampling area of 0.25 m^2, were collected in riffles within each reach by using a 425-µm mesh Slack sampler. Bed sediment within the sample area was disturbed to a depth of approximately 10 cm for approximately one minute. Large rocks were scrubbed to remove any adhering organisms. The five samples then were composited and packaged for shipment. The samples were submitted to the Biological Unit of the NWQL for taxonomic determination. The resulting data was entered into a database for further manipulation (see **appendix 2** for raw data). Macroinvertebrate metrics were calculated and categorized according to richness, composition, tolerance, and feeding measures (**table 2**).

ANALYSIS

Macroinvertebrate identification and presence–absence data were entered into a database and sorted for further analysis. An unweighted-paired-grouping-method (UPGM) cluster analysis using arithmetic means was applied to Bray–Curtis distance matrices and was performed by using lowest identifiable taxa data. Dendrograms were generated to aid in relating clusters of sites. UPGM clustering refers to the measurement of the distance between two clusters as measured by the average of all sampling units within each group (Pielou, 1984; Ludwig and Reynolds, 1988). The resultant dendrogram grouped the sites on the basis of dissimilarities (**fig. 3**). Groupings that have larger Bray–Curtis dissimilarity values (approaching 1) are more dissimilar.

Table 2. Biological metrics and expected response of macroinvertebrates to perturbation

[Data modified from Kerans and Karr (1994); Barbour and others (1996); and Fore and others (1996). EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera]

Biological metric	Definition and remarks	Expected response to increasing perturbation
Abundance category		
EPT abundance	Number of EPT individuals	Decrease
Composition category		
Margalef diversity index (lowest practical taxonomic level of identification)	Measure of species richness (measured to the lowest practical taxonomic level of identification).	Decrease
Margalef diversity index (family level)	Measure of species richness (measured to the family level of identification).	Decrease
Shannon diversity index	Index that uses richness and evenness to measure general diversity and composition.	Decrease
Percentage Chironomidae	Percentage midge larvae	Increase
Percentage Ephemeroptera	Percentage mayfly nymphs	Decrease
Percentage Plecoptera	Percentage stonefly nymphs	Decrease
Percentage Trichoptera	Percentage caddisfly larvae	Decrease
Percentage Oligochaeta	Percentage aquatic worms	Variable
Ratio of EPT to Chironomidae abundances	Measure of balance between two indicator groups	Decrease
Feeding category		
Percentage filterers	Percentage of macrobenthos that filter from water column or sediment	Variable
Percentage collectors (gatherers)	Percentage of macrobenthos that feed by gathering	Variable
Percentage predators	Percentage of macrobenthos that feed upon other organisms	Variable
Percentage scrapers	Percentage of macrobenthos that scrape or graze on periphyton	Decrease
Percentage shredders	Percentage of macrobenthos that shred leaf material	Decrease
Richness category		
Total taxa richness (lowest practical taxonomic level of identification)	Measure of overall variety of macroinvertebrates at lowest taxa identified	Decrease
Total taxa richness (family level)	Measure of overall variety of macroinvertebrates at family level of identification.	Decrease
EPT taxa richness	Number of EPT taxa represented	Decrease
Tolerance category		
Hilsenhoff family-level biotic index	Index that uses tolerance values to weight family-level identifications to evaluate organic pollution.	Increase
Percentage two dominant taxa	Percentage composition of the two most abundant taxa	Increase
Ratio of Baetidae to Ephemeroptera abundances	Relative abundance of pollution-tolerant mayflies	Increase

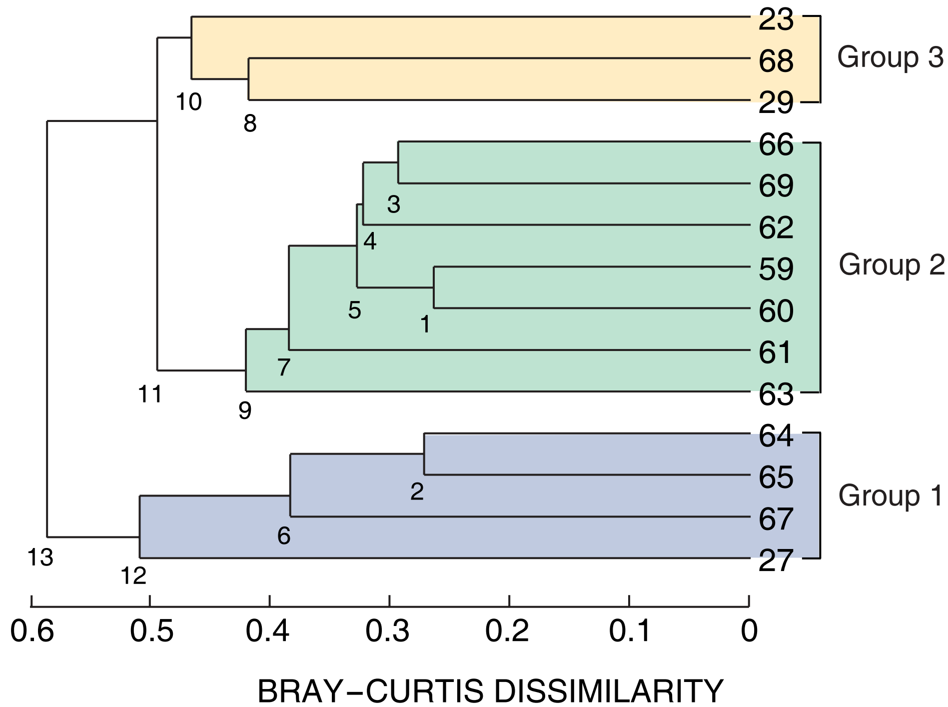

Figure 3. Cluster analysis (unweighted-paired-grouping method) using arithmetic means of macroinvertebrate presence–absence data. Values approaching 1 are more dissimilar. Nodes (13, 11, 10, 12, and others) represent clusters and facilitate assessment of dissimilarity. Group 1 sites are considered "urban impacted"; group 2 sites are "non-impacted"; group 3 sites are considered to be possibly anomalous compared to other two groups. (See fig. 1 and appendix 1 regarding sampling sites.)

Variables for water chemistry (major ions and nutrients) and bed-sediment chemistry (trace elements) that were below detection limits were removed from analysis because of the limited number of sites in the data set. A correlation table of the significant variables ($p < 0.05$, $r > |0.7|$) against population density was generated to determine those variables associated with urbanization for further analysis (**table 3**).

Population, road, and storm-drain densities were calculated by using data provided by the Municipality of Anchorage. Population density was defined as number of persons/mi^2 of basin; road density was defined as linear miles of road per square mile of basin; storm-drain density was defined as miles of storm drains per square mile of basin. The ratio of population density to road density, or PDRD ratio, was calculated as the number of persons per mile of road. Each of these calculations incorporates all basin area upstream from each site.

Local regression analysis, performed by using the statistical package S-Plus 2000 (Mathsoft, Inc., 2000), was used to examine the variables associated with urbanization (measured as population density in this study) for the presence of a threshold response or of a linear response. Threshold responses, visually identified by a breakpoint in or change in slope of a smooth-fit line, suggest a point at which further increases in population density could have a significant effect on stream condition with respect to the particular constituent or metric. Scatterplot smoothing was used to remove noise (that is, extraneous information that reduces our ability to see patterns in the data) from a data set and to produce a more easily interpreted fit. After the threshold had been identified visually on the plot, the breakpoint was tested by determining if the slopes of the two lines converging at the breakpoint differed significantly. A *t*-test (Zar, 1996) was used to check the equality of two population regression coefficients; a linear response indicates that any increase in population density (the independent variable, x) relates to an increase or decrease (depending on the variable) in the dependent variable (y) in a linear fashion without a significant change in the slope of the line at a breakpoint.

Table 3. Coefficients of correlation between each metric or constituent or field property and population density

[Blue shading indicates that correlation is significant at $p < 0.05$, n =14. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera]

Biological metric or constituent	Coefficient of correlation with population density
Biological variables	
Margalef diversity index (lowest practical taxonomic level of identification)	-0.78
Margalef diversity index (family level)	-.36
Shannon diversity index (lowest practical taxonomic level of identification)	-.81
Total abundance	-.18
EPT abundance	-.33
Hilsenhoff family-level biotic index	.78
Percentage Chironomidae	-.23
Percentage Ephemeroptera	-.38
Percentage Plecoptera	-.43
Percentage Trichoptera	-.36
Percentage Oligochaeta	.71
Percentage filterers	-.34
Percentage collectors	.1
Percentage predators	-.56
Percentage scrapers	-.63
Percentage shredders	-.37
Total taxa richness (lowest practical taxonomic level of identification)	-.73
Total taxa richness (family level)	-.56
Percentage two dominant taxa	.82
Percentage EPT	-.62
EPT taxa richness	-.85
Ratio of EPT to Chironomidae abundances	-.34
Ratio of Baetidae to Ephemeroptera abundances	.65
Chlorophyll-*a*	.35
Water chemistry and field properties	
Silica	.66
Calcium	.61
Chloride	.97
Sodium	.92
Potassium	.95
Magnesium	.84
Sulfate	.27
Total dissolved solids	.76
Organic carbon, dissolved	.74
Discharge	-.15
Specific conductance	.76
pH	-.04
Temperature	.36
Oxygen, dissolved	-.17
Mercury	-.26
Copper	.64
Sulfur	.64
Cobalt	.41
Chromium	.55
Bed-sediment chemistry	
Phosphorus	.15
Sodium	.01
Magnesium	.25
Potassium	-.27
Iron	.85
Calcium	.04
Aluminum	-.15
Selenium	-.27
Arsenic	.86
Cadmium	.97
Silver	.81
Zinc	.98
Lead	.98
Nickel	.5
Molybdenum	.05
Manganese	.84

RESULTS

A UPGM cluster analysis of macroinvertebrate-species abundance data using Bray–Curtis distance matrices is shown in figure 3. The sites separated into three primary groupings based on cluster analysis. These groupings illustrate a delineation between urban-impacted (group 1) and nonimpacted sites (group 2), as well as substantiate the differences between Ship Creek (group 3) and the rest of the basins in the Anchorage Bowl. The South Fork of Campbell Creek site (site 23, group 3) appears anomalous, possibly due to a different sampling time compared to the other sites. The PDRD ratio appears to support the separation of sites in group 1 from those in groups 2 and 3 but does not distinguish group 3 from group 2 (table 1, fig. 3, **fig. 4**). Storm-drain density also supports the separation of group 1 from groups 2 and 3. All group 1 sites had storm-drain densities ≥0.45.

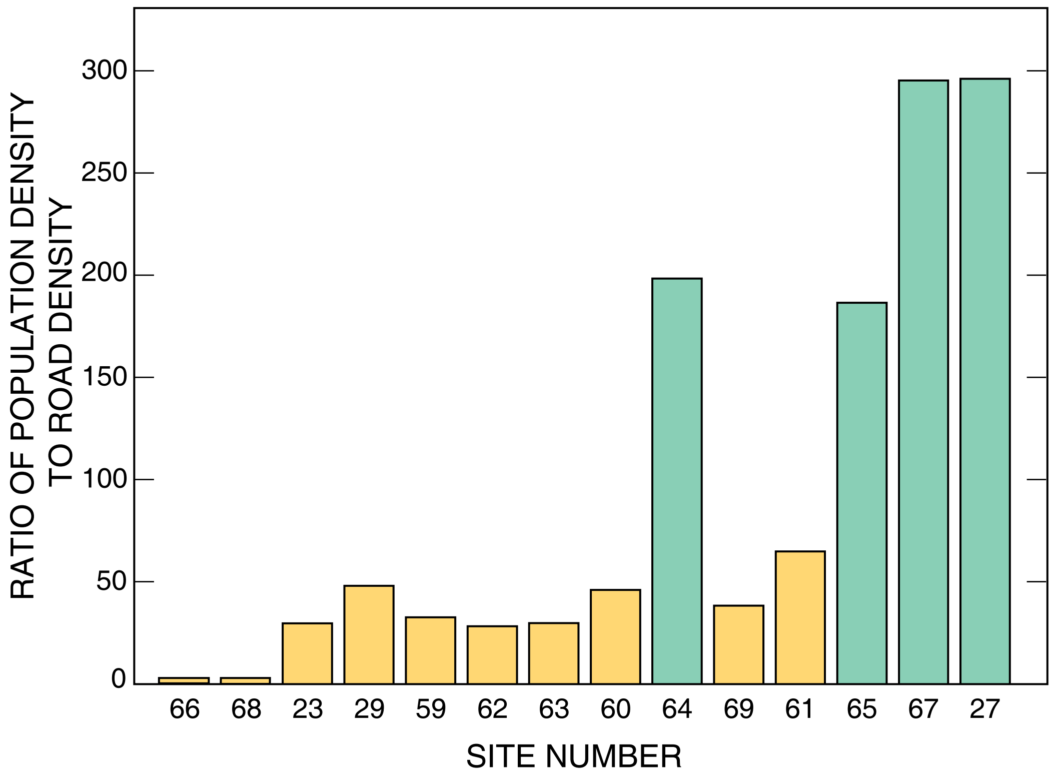

Figure 4. Ratio of population density to road density, comparing group 1 sites (green), which are urban impacted, with groups 2 and 3 sites (yellow), which are nonimpacted and anomalous, respectively. (See fig. 1 and appendix 1 regarding sampling sites.)

Correlation coefficients between chosen metrics or constituents and population density are shown in table 3 ($p < 0.05$, $n = 14$). Of these variables, 12 biological variables (appendix 2 and **appendix 3**), 12 water-chemistry variables (**appendix 4**), and 7 trace-element-in-bed-sediments variables (**appendix 5**) were shown to be significant ($p < 0.05$).

The PDRD ratio was greatest for those sites rated as urban impacted (table 1, fig. 4). The ratios for sites 27, 67, 65, and 64 (members of group 1 in the cluster analysis, fig. 3) were an order of magnitude higher than for all other sites, which had PDRD ratios of less than 70. No difference with respect to the PDRD ratio was evident between UPGM cluster groupings 2 and 3.

Locally weighted regression analysis was performed on 31 macroinvertebrate metrics, water-chemistry variables, field properties, and bed-sediment variables that correlated significantly ($p < 0.05$) with population density (table 3). Of these 31 variables, 11 showed a threshold response of the constituent to population densities when plotted and tested for significance (**fig. 5**, **fig. 6**, **fig. 7**, **table 4**), and 7 exhibited a linear response (no significant breakpoint in the line) (**fig. 8**, table 4).

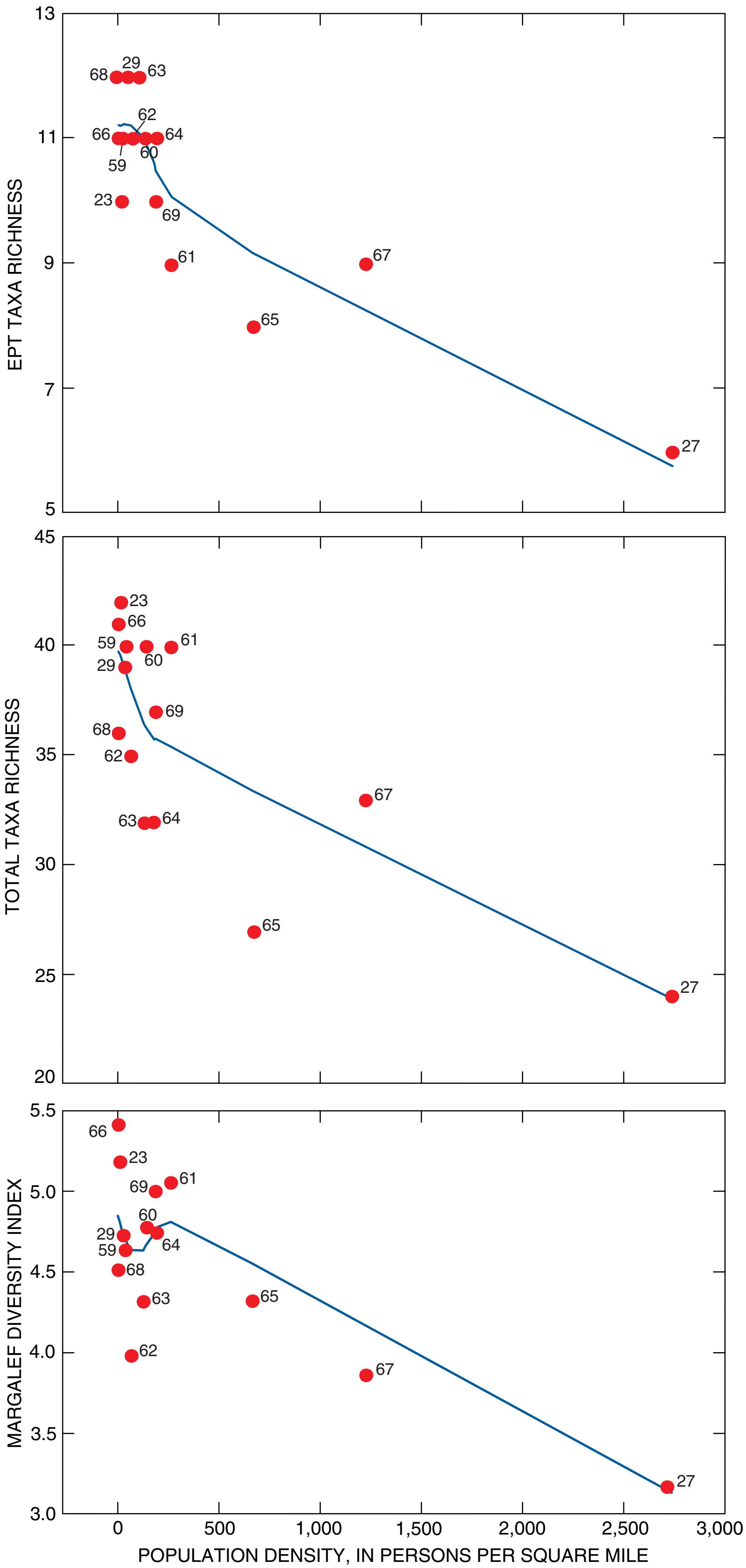

Figure 5. Variable-span bivariate smoothed scatterplot of three significant biological variables ($p < 0.05$, $n = 14$), showing threshold response against population density. Total taxa richness and Margalef diversity index: both at lowest practical taxonomic level of identification. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera. (See fig. 1 and appendix 1 regarding sampling sites.)

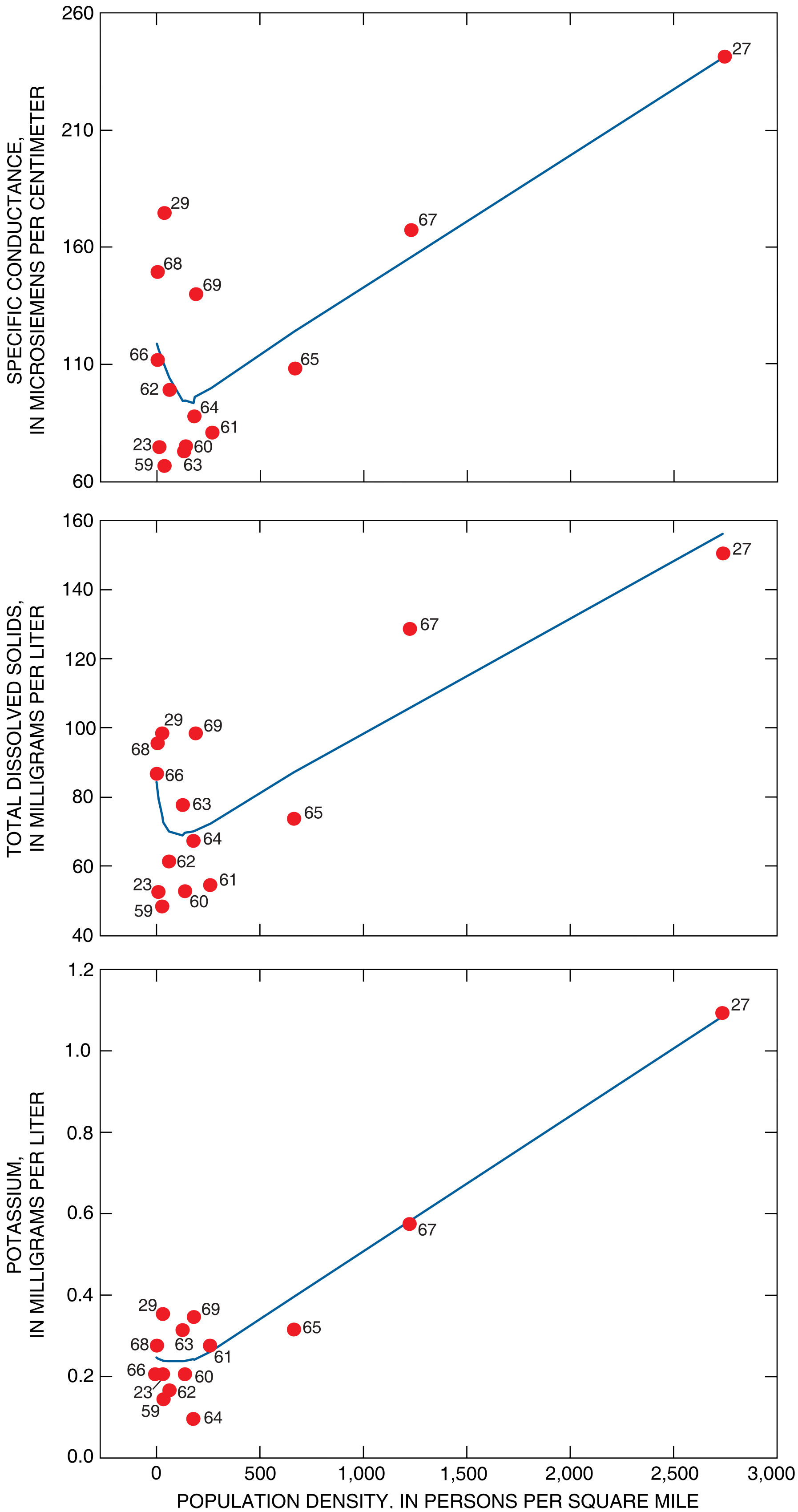

Figure 6. Variable-span bivariate smoothed scatterplot of four significant water-chemistry variables ($p < 0.05$, $n = 14$), showing threshold response against population density. (See fig. 1 and appendix 1 regarding sampling sites.)

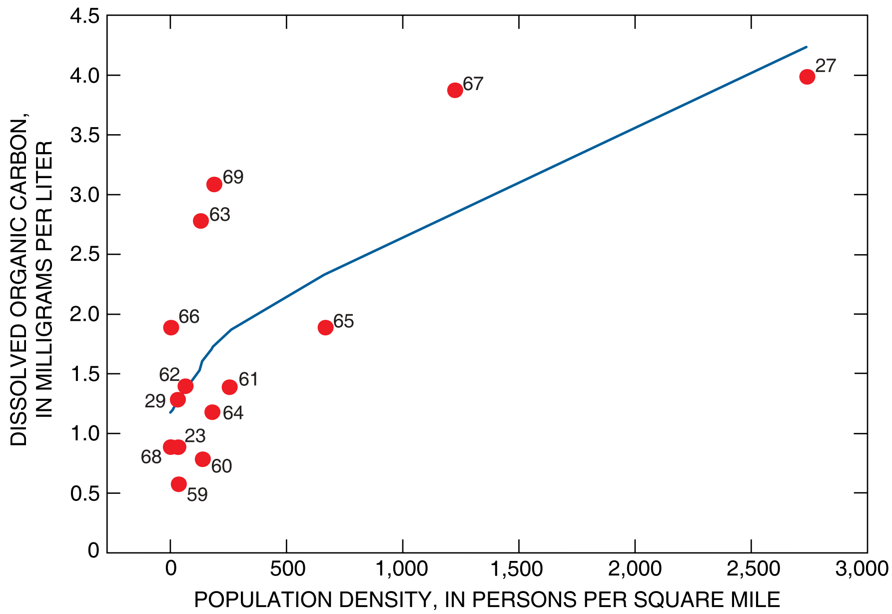

Figure 6.—*Continued*

DISCUSSION

The Bray–Curtis distance measures revealed three distinguishable groupings. Group 1 or the "urban-impacted" group is under the 12th node (dissimilarity index, 0.510). These sites (27, 67, 65, and 64) have the relatively high population densities, road densities, and storm-drain densities (≥0.45). Each of these sites also had PDRD ratios greater than 185. The separation of these sites is due primarily to the presence of oligochaetes (worms) and mayflies of the family Baetidae, both of which commonly are associated with diminished water quality. This is supported further by the metric percentage composition of the two most common taxa (PDT2), higher values of which commonly are associated with impaired water quality (Barbour and others, 1999). Because all the group 1 sites had higher PDT2 values than all other sites, these sites were considered to be urban-impacted sites. At these sites, we observed higher levels of fine sediments in the bed materials, which make better oligochaete habitat (Thorp and Covich, 1991). The two major families, Naididae and Tubificidae, continuously feed on the sediments through which they burrow. Algae and other periphytic materials are the primary food source for most naidids, whereas bacteria are the preferred food source for most tubificids (Brinkhurst and Gelder, 1991). Both these food sources are found in abundance at urban-impacted sites. Epiphytic algal blooms can be related to an increase in nutrients (lawn fertilizers, etc.) entering the stream after a storm event via storm drains, and bacteria in streams are most commonly associated with sewage or other organic pollution (such as from a large population of waterfowl, livestock, etc.). Both of these nutrient sources are common at or near the group 1 sites.

Sites in group 2 or the "nonimpacted" group (63, 61, 60, 59, 62, 69, 66), which is beneath the ninth node (dissimilarity index, 0.421), generally have considerably lower population, road, and storm-drain densities than sites have in the urban-impacted group. Two sites in the group (61 and 69) do have relatively high population densities, but this is offset by the lower PDRD ratio when compared to the urban-impacted sites. The primary macroinvertebrate groups driving this separation in the cluster analysis are those sensitive to perturbation—the mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera).

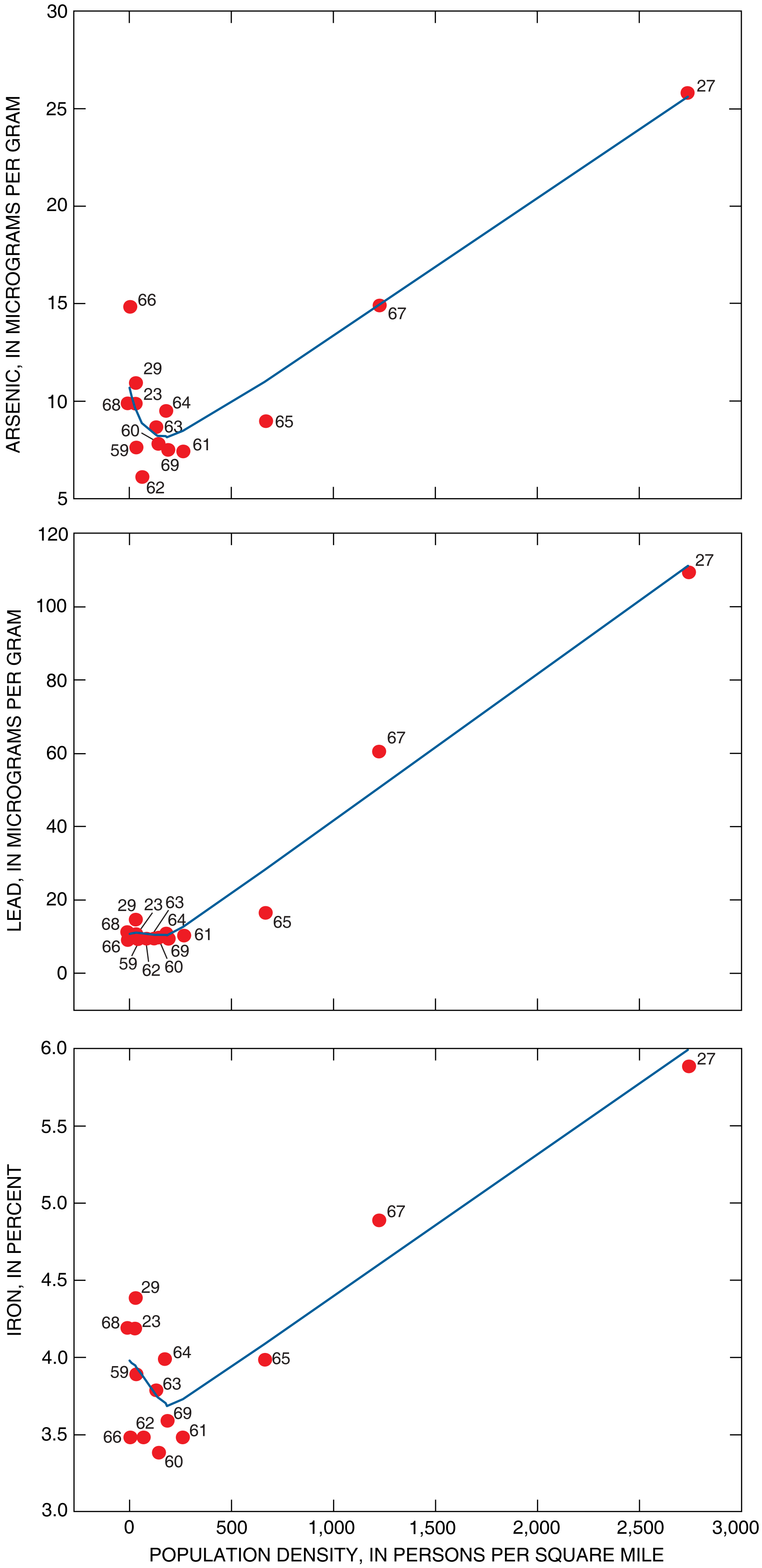

Figure 7. Variable-span bivariate smoothed scatterplot of four significant trace-elements-in-bed-sediments variables ($p < 0.05$, $n = 14$), showing threshold response against population density. (See fig. 1 and appendix 1 regarding sampling sites.)

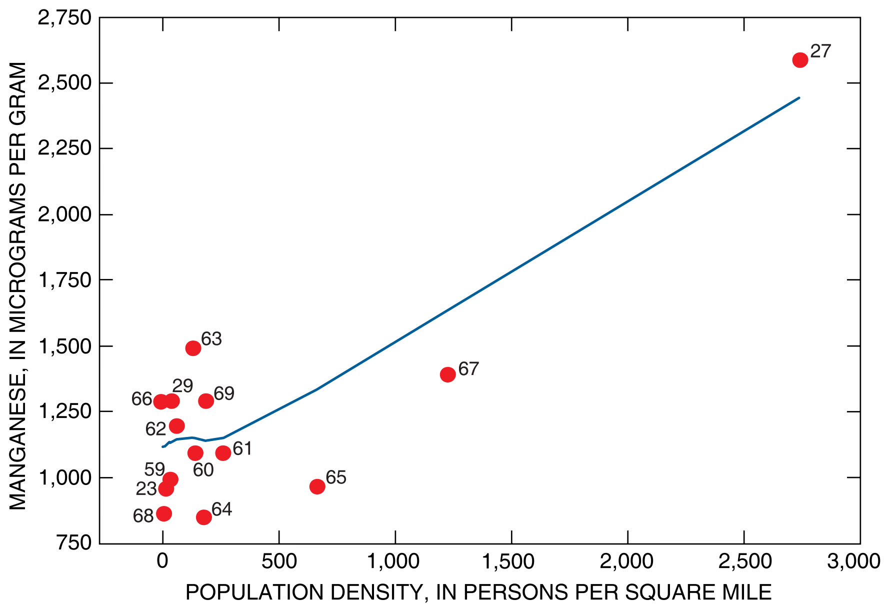

Figure 7.—*Continued*

Table 4. Coefficients of determination (r^2) as calculated by linear and local regression analysis and significance (p)

[Threshold population-density range: Range of values that includes breakpoint. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera. <, less than; —, not applicable]

Biological metric or constituent	Linear-regression model, coefficient of determination, r^2	Significance, p	Local-regression model, coefficient of determination, r^2	Threshold population-density range (persons per square mile)	Type of response
Biological metrics					
Margalef diversity index[1]	0.62	0.0008	0.78	125–137	Threshold
Hilsenhoff family biotic index	.61	.001	.57	—	Linear
Percentage Oligochaetes	.52	.003	.63	—	Linear
Percentage dominant two taxa	.68	.0002	.27	—	Linear
EPT taxa richness	.72	.001	.8	262–662	Threshold
Total taxa richness[1]	.54	.002	.26	125–137	Threshold
Water chemistry (major ions)					
Chloride	.94	<.0001	.98	—	Linear
Potassium	.9	<.0001	.91	177–183	Threshold
Magnesium	.7	.002	.79	—	Linear
Sodium	.84	<.0001	.93	—	Linear
Conductivity	.55	.002	.68	125–137	Threshold
Dissolved organic carbon	.55	.002	.66	125–137	Threshold
Total dissolved solids	.58	.001	.6	177–183	Threshold
Bed-sediment chemistry (trace elements)					
Lead	.96	<.0001	.99	177–183	Threshold
Zinc	.95	<.0001	.99	—	Linear
Arsenic	.75	<.0001	.92	32–60	Threshold
Iron	.73	<.0001	.81	137–177	Threshold
Manganese	.72	.0001	.89	125–137	Threshold

[1]Lowest practical taxonomic identification.

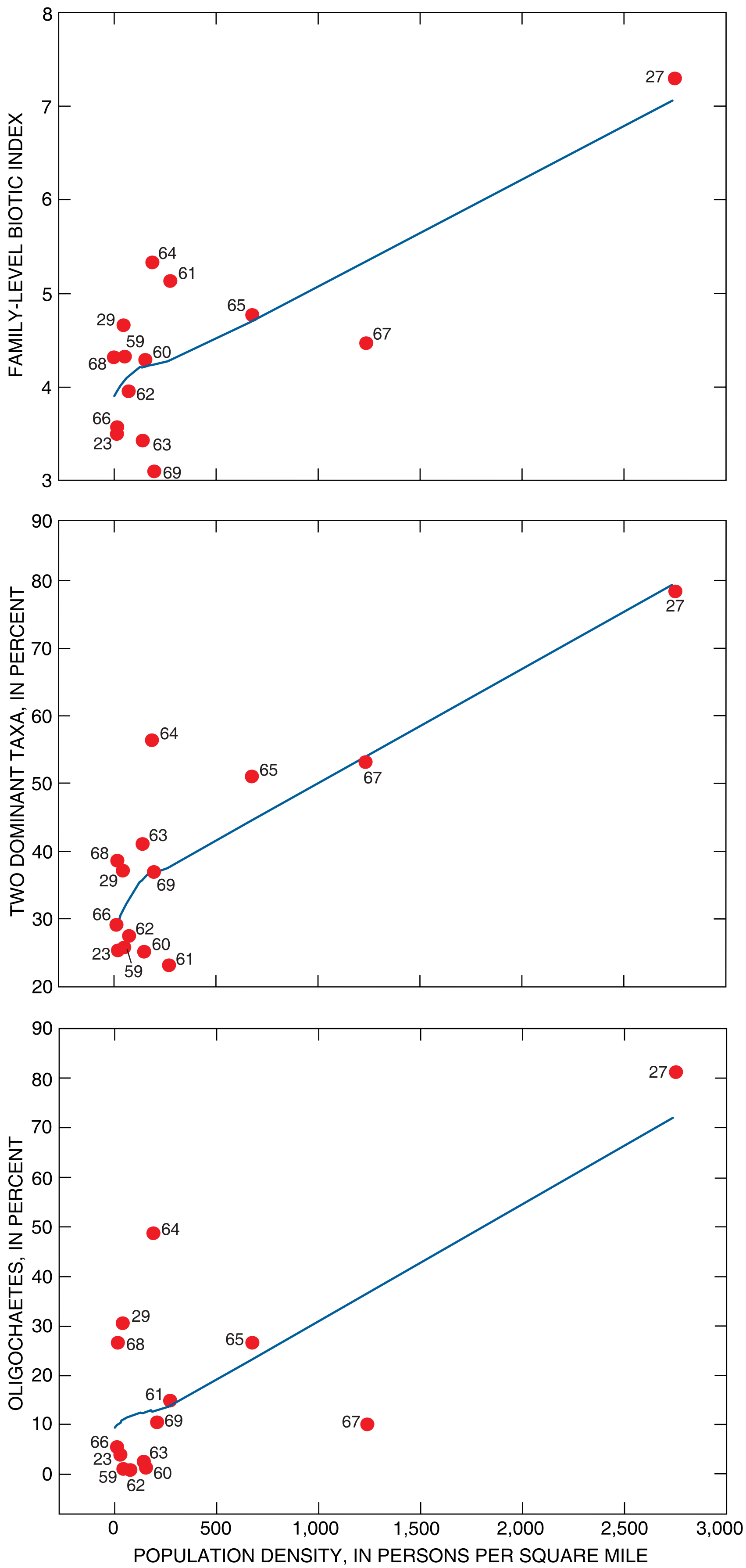

Figure 8. Variable-span bivariate smoothed scatterplot of seven other significant biological and chemical variables ($p < 0.05$, $n = 14$), showing linear response against population density. (See fig. 1 and appendix 1 regarding sampling sites.)

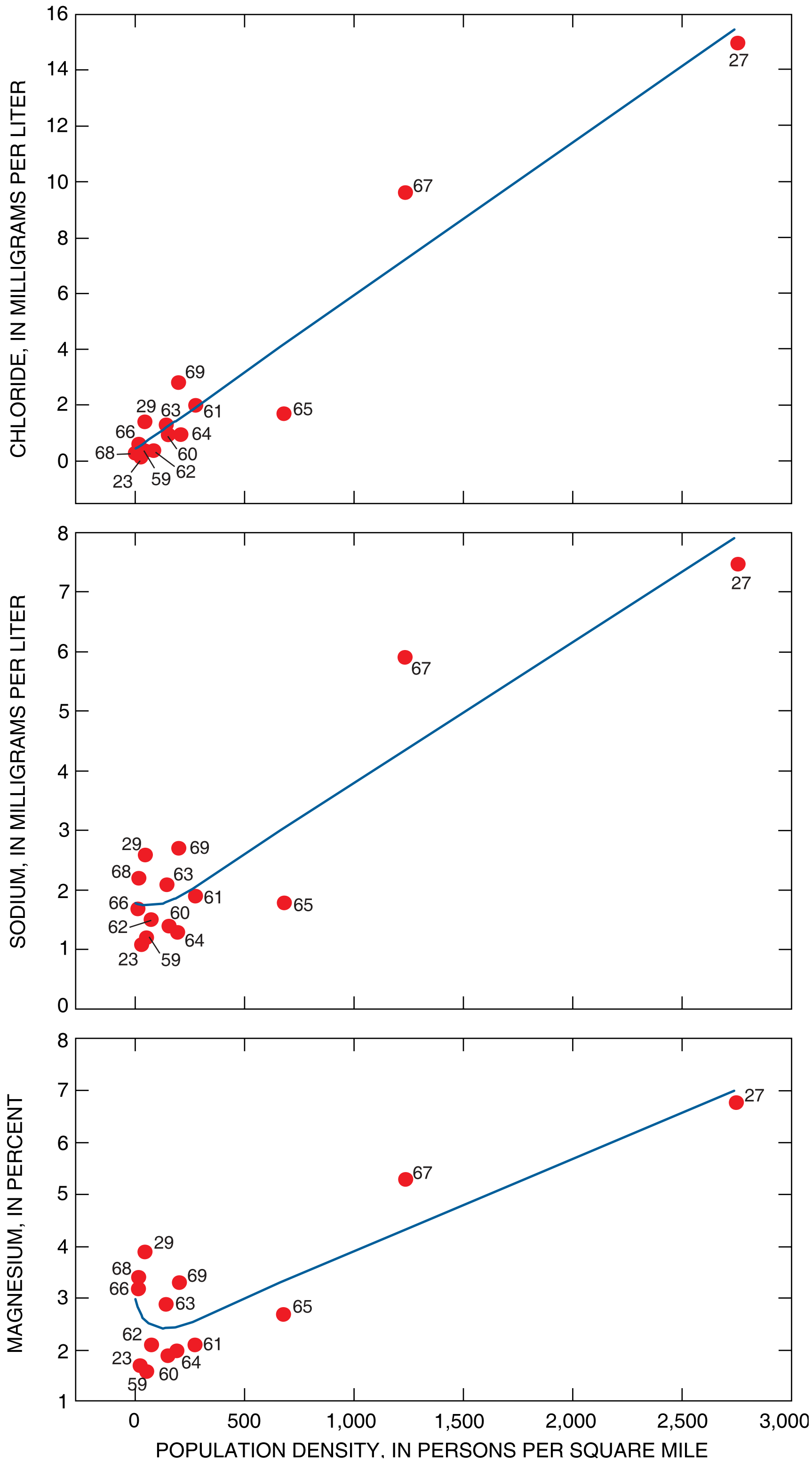

Figure 8.—*Continued*

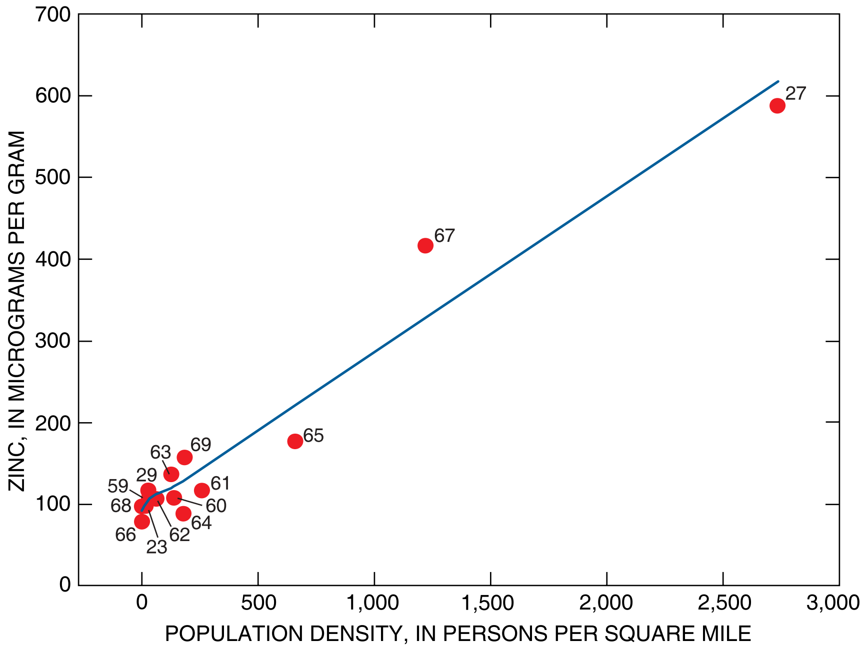

Figure 8.—*Continued*

The last group in the cluster analysis is made up of the two Ship Creek sites (29 and 68) and the reference site for Campbell Creek (site 23). The Ship Creek sites are considered anomalous because of the size of the basin compared to the other basins in the study and the fact that the creek has been regulated through the building of two small dams. Salmon are no longer able to pass to the upper site (68) because of obstructions. Therefore, the replenishment of instream nutrients from salmon carcasses no longer occurs, depriving many macroinvertebrates of an important food source and thereby limiting occurrence and abundance. Another confounding factor relates to the drying of the streambed at the upper site (29) during winter low flows in some years. Discharge for the Ship Creek sites is also considerably greater than the other sites. The South Fork of Campbell Creek site (23) grouped with the Ship Creek sites, probably because of a shift in macroinvertebrate-community structure influenced by the date at which the sample was collected compared to the other sites. Food-type availability could be a driving factor in the separation of this site from group 2. This site was sampled in July and would not have had the abundance of leaf litter found during the later sampling period when all other sites were sampled. That a shift from a feeding regime dominated by grazing (of algae) to one dominated by shredding (of leaf litter) probably had not yet taken place is shown by the relative percentages of scrapers and shredders. We predict that an upstream site having few known urban factors would fit into group 2 if sampled during the same time period.

The PDRD ratio and storm-drain density appear useful for separation of urban-impacted from nonimpacted sites. High PDRD ratios (>70) are associated with areas that have a high percentage impervious cover. As population densities increase, more roads, parking, and housing are required to meet basic needs. Accumulation of pollutants (deicing salts, petroleum products, combustion byproducts, etc.) on road and parking surfaces has been modeled for small watersheds and was shown to have a potentially negative impact on the quality of water in streams when runoff events occur (Novotny and others, 1985). The potentially greater input of pollutants into streams in areas of increased population density and hence high road density may have a significant role in the separation of urban-impacted from nonimpacted areas. Group 1 sites had storm-drain densities ≥0.45. Increased storm-drain density adds to the number of artificial channels that in turn rapidly pass water to the streams, thereby circumventing the natural hydrologic cycle (May and others, 1997). This rapid channeling diminishes infiltration and storage of water in shallow aquifers and hence reduces baseflows during periods of reduced precipitation. Reduced baseflows have the effect of reducing habitat suitable for aquatic species, thereby negatively impacting the “natural state” of the stream.

Regression analysis of the most significant variables, with respect to population density, revealed that the majority exhibited a threshold response to urbanization (table 4, fig. 5, fig. 6, fig. 7). This finding suggests that streams in the Anchorage Bowl are able to accommodate the effects of urbanization only up to a point; beyond that, stream structure and function are impaired.

Three of the six biologically significant variables ($p < 0.05$, $r^2 > 0.5$) showed threshold responses (table 4). Two variables (EPT taxa richness and total taxa richness) are richness measures, and one (Margalef diversity) is an index of the macroinvertebrate community. These biological variables tend to support the separation of urban-impacted from nonimpacted sites revealed by the cluster analysis, especially when related to the PDRD ratio rather than exclusively to population density. Both taxa richness and macroinvertebrate diversity decrease in a downstream direction. In contrast, the percentage oligochaetes, the Hilsenhoff family-level biotic index (FBI) (Hilsenhoff, 1988), and the PDT2 increase downstream; all three exhibit linear responses to population density (fig. 8, table 4). Oligochaetes were generally one of the major components making up the PDT2 at the urban-impacted sites. The FBI, which is a measure of organic pollution and the subsequent response by macroinvertebrates based on tolerance values, also increased downstream. FBI values greater than 5 suggest the probability of organic pollution. Sites that had PDRD ratios greater than 50 had FBI values greater than 5. Urban-impacted sites tended to have fewer species of more-tolerant, generalist organisms, whereas nonimpacted sites had greater numbers of more-sensitive species. Negative impact in general, with respect to the biological variables exhibiting a threshold response, appears to occur near population densities of 140 persons/mi^2. EPT taxa richness shows a break in slope between 262 and 662 persons/mi^2, but this threshold is due in part to the occurrence of the generally perturbation-tolerant Baetid family of mayflies (Ephemeroptera). Removal of this group from the metric calculations increases the sensitivity of the measure and brings it in line with the other two threshold variables.

The major ions (inorganic constituents in water samples) found to be significant with respect to population density include magnesium, sodium, potassium, and chloride (table 4). Magnesium, sodium, and chloride are found in low concentrations in natural streams. The elevated levels found in the urban-impacted sites are probably a result of the application of deicing salts and subsequent runoff and possibly also a result of leakage of domestic wastewater. The linear trends in the fitted curves of the analyses for these three constituents (fig. 8, table 4) suggest that any increase in population density would result in a corresponding increase in the concentration of these constituents in water in Anchorage. Potassium, which showed a threshold response (fig. 6), is an essential element for growth in both plants and animals. Elevated levels in urban areas are generally attributed to nonpoint-source pollution due to the application of fertilizers. The variables conductivity, total dissolved solids, and dissolved organic carbon also showed threshold responses (fig. 6, table 4). The breakpoints for water-chemistry variables reflect the threshold range for the biological metrics (table 4).

Significant trace elements in bed sediments (arsenic, lead, iron, manganese) (fig. 7, table 4), displayed a threshold-response curve with respect to population density (fig. 7). Although Klein (1979) considered the constituents lead and zinc to be good urban-signature constituents with respect to impervious area, zinc exhibited a linear response to population density in this study (fig. 8, table 4). The primary sources for both metals are vehicles, piping, and commercial and industrial nonpoint-source activity. Arsenic, iron, and manganese were more likely from natural sources, but because of organic pollution and the reducing (anaerobic) environment it helps to create in the sediments, they were more readily detected in the highly urbanized areas. The breakpoint for lead, at a population density between 60 and 125 persons/mi^2, suggests that it is a potentially sensitive urbanization variable. Iron and arsenic levels were probably at background levels at upstream sites; changes in concentration were noted at urban-impacted site 65 and increased in a downstream direction. Manganese was in line with the biological metrics; its regression shows a breakpoint at a population density between 125 and 137 persons/mi^2 (fig. 7).

CONCLUSIONS

Site-based reconnaissance data allowed us to visualize the effect of urbanization on stream macroinvertebrates in Anchorage. Population density appears to be a reasonable surrogate of urbanization, but further testing of the PDRD ratio as a rapid urbanization variable is needed. A threshold effect was observed for most of the significant variables. Adversely impacted sites typically had higher human population, road, and storm-drain densities. As trace-element and salt concentrations increased with increasing population, road, and storm-drain densities, macroinvertebrate diversity decreased. PDRD ratios greater than 70, road densities greater than 4.0 mi/mi^2, and(or) population densities of 125–150 persons/mi^2 (a conservative approximation) can be used to warn of the heightened potential of urbanization-induced degradation of streams in Anchorage. Exceptions to this are the Ship Creek sites, which may have skewed the data. Contributing factors may include disproportionate basin size and relative lack of development normally associated with urbanization over much of its area, localized industrialization, impoundments, and cessation of flow during winter months. Incremental areas between sites also should be examined for integration into calculations to determine if a more robust explanation can be generated.

The U.S. Census Bureau (1990) defines urban areas as having minimum population densities of 1,000 persons/mi^2; this criterion is met by only two of the sites in this study, though many of the other sites meet criteria to be designated “urban fringe”. Wear and others (1998) suggested that two main areas along an urban–rural gradient may significantly impact water quality—at the edge of urban expansion and at the most undeveloped parts of the basin. According to results of our study, stream impairment appears to begin within the urban fringe. Areas having population densities of 125–150 persons/mi^2 appear to be the first to start showing signs of stream impairment. We readily could see evidence of changes in the streams and surrounding riparian areas at those sites near or at this threshold. For example, channels had been modified, the riparian zones were altered, manmade litter was observed, and the distance between roads and streams had decreased. The PDRD ratio complemented the results of the cluster analysis, at least with respect to differentiating urban-impacted and nonimpacted sites. Further study of this ratio as a rapid assessment of potential urban impact is warranted.

REFERENCES CITED

Barbour, M.T., Gerritsen, J., Griffith, G.E., Frydenborg, R., McCarron, E., White, J.S., and Bastian, M.L., 1996, A framework for biological criteria for Florida streams using benthic macroinvertbrates: Journal of the North American Benthological Society, v. 15, no. 2, p. 185–211.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers—Periphyton, benthic macroinvertebrates, and fish (2d ed.): U.S. Environmental Protection Agency EPA 841–B–99–002.

Brabets, T.P., Nelson, G.L., Dorava, J.M., and Milner, A.M., 1999, Water-quality assessment of the Cook Inlet Basin, Alaska—Environmental setting: U.S. Geological Survey Water-Resources Investigations Report 99–4025, 65 p.

Brinkhurst, R.O., and Gelder, S.R., 1991, Annelida—Oligochaeta and Branchiobdellida, *in* Thorp, J.H., and Covich, A.P., eds., Ecology and classification of North American freshwater invertebrates: Academic Press, p. 401–435.

Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993, Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment program: U.S. Geological Survey Open-File Report 93–406, 66 p.

Fore, L.S., Karr, J.R., and Wisseman, R.W., 1996, Assessing invertebrate responses to human activities—Evaluating alternative approaches: Journal of the North American Benthological Society, v. 15, no. 2, p. 212–231.

Garie, H.L., and McIntosh, A., 1986, Distribution of benthic macroinvertebrates in a stream exposed to urban runoff: Water Resources Bulletin, v. 22, no. 3, p. 447–451.

Hilsenhoff, W.H., 1988, Rapid field assessment of organic pollution with a family-level biotic index: Journal of the North American Benthological Society, v. 20, no. 1, p. 65–68.

Hynes, H.B.N., 1970, The ecology of running waters: University of Toronto Press, Toronto, 555 p.

Kerans, B.L., and Karr, J.R., 1994, A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley: Ecological Applications, v. 4, p. 768–785.

Klein, R.D., 1979, Urbanization and stream quality impairment: Water Resources Bulletin, v. 15, no. 4, p. 948–963.

Ludwig, J.A., and Reynolds, J.F., 1988, Statistical ecology—A primer on methods and computing: Wiley, 337 p.

Mathsoft, Inc., 2000, S-Plus 2000 Professional—Release 3: Mathsoft, Inc. [CD–ROM].

May, C.W., Welch, E.B., Horner, R.R., Karr, J.R., and Mar, B.W., 1997, Quality indices for urbanization effects in Puget Sound lowland streams: Department of Civil Engineering, University of Washington, Water Resources Series Technical Report no. 154, 229 p.

Milner, A.M., and Oswood, M.W., 1989, Macroinvertebrate distribution and water quality in Anchorage streams: Institute of Arctic Biology, University of Alaska at Fairbanks, 48 p.

Municipality of Anchorage, 1996, Population and housing sampling frame—By census tracts: Municipality of Anchorage Community Planning and Development, 6 p.

Novotny, V., Sung, H.M., Bannerman, R., and Baum, K., 1985, Estimating nonpoint pollution from small urban watersheds: Journal of the Water Pollution Control Federation, v. 57, no. 4, p. 339–348.

Pielou, E.C., 1984, The interpretation of ecological data: Wiley, 263 p.

Porter, S.D., Cuffney, T.F., Gurtz, M.E, and Meador, M.R., 1993, Methods for collecting algal samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93–409, 39 p.

Shelton, L.R., 1994, Field Guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94–455, 42 p.

Shelton, L.R., and Capel, P.D., 1994, Guidelines for collecting and processing samples of stream bed sediment for analysis of trace elements and organic contaminants for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94–458, 20 p.

Thorp, J.H., and Covich, A.P., 1991, Ecology and classification of North American freshwater invertebrates: Academic Press, 911 p.

U.S. Census Bureau, 1990, Population and housing unit counts: 1990 Census of Population and Housing CPH–2–3, 101 p.

Wear, D.N., Turner, M.G., and Naiman, R.J., 1998, Land cover along an urban–rural gradient—Implications for water quality: Ecological Applications, v. 8, no. 3, p. 619–630.

Whiting, E.R., and Clifford, H.F., 1983, Invertebrates and urban runoff in a small northern stream, Edmonton, Alberta, Canada: Hydrobiologia, v. 102, p. 73–80.

Winter, J.G., and Duthie, H.C., 1998, Effects of urbanization on water quality, periphyton and invertebrate communities in a southern Ontario stream: Canadian Water Resources Journal, v. 23, no. 3, p. 245–257.

Zar, J.H., 1996, Biostatistical analysis: Prentice Hall, 662 p.

APPENDIXES

Appendix 1. Cook Inlet Basin National Water-Quality Assessment site-numbering system

[Site numbers used in this report (shown in **bold** and shaded blue; see fig. 1 and fig. 2 for site locations) follow numbering system for stream-gaging stations that was introduced in National Water-Quality Assessment Cook Inlet Basin environmental-setting report (Brabets and others, 1999). Total number of sites listed reflects assignments as of this writing. Sequence of site numbers generally parallels order used in U.S. Geological Survey data-station identification]

Site number	U.S. Geological Survey station	
	Number	Name
1	15238820	Barabara Creek near Seldovia
2	15239500	Fritz Creek near Homer
3	15239000	Bradley River near Homer
4	15239050	Middle Fork Bradley River near Homer
5	15239900	Anchor River near Anchor Point
6	15240000	Anchor River at Anchor Point
7	15241600	Ninilchik River at Ninilchik
8	15242000	Kasilof River near Kasilof
9	15244000	Ptarmigan Creek at Lawing
10	15246000	Grant Creek near Moose Pass
11	15248000	Trail River near Lawing
12	15254000	Crescent Creek near Cooper Landing
13	15258000	Kenai River at Cooper Landing
14	15260000	Cooper Creek near Cooper Landing
15	15264000	Russian River near Cooper Landing
16	15266300	Kenai River at Soldotna
17	15266500	Beaver Creek near Kenai
18	15267900	Resurrection Creek near Hope
19	15271000	Sixmile Creek near Hope
20	15272280	Portage Creek at Portage Lake outlet near Whittier
21	15272550	Glacier Creek at Girdwood
22	15273900	South Fork Campbell Creek at Canyon Mouth near Anchorage
23	15274000	**South Fork Campbell Creek near Anchorage**
24	15274300	North Fork Campbell Creek near Anchorage
25	15274600	Campbell Creek near Spenard
26	15275000	Chester Creek at Anchorage
27	15275100	**Chester Creek at Arctic Boulevard at Anchorage**
28	15276000	Ship Creek near Anchorage
29	15276570	**Ship Creek below powerplant at Elmendorf Air Force Base**
30	15277100	Eagle River at Eagle River
31	15277410	Peters Creek near Birchwood
32	15281000	Knik River near Palmer
33	15282000	Caribou Creek near Sutton
34	15284000	Matanuska River near Palmer
35	15290000	Little Susitna River near Palmer
36	15291000	Susitna River near Denali
37	15291200	Maclaren River near Paxson
38	15291500	Susitna River near Cantwell
39	15292000	Susitna River at Gold Creek
40	15292400	Chulitna River near Talkeetna
41	15292700	Talkeetna River near Talkeetna
42	15294005	Willow Creek near Willow
43	15294010	Deception Creek near Willow
44	15294100	Deshka River near Willow
45	15294300	Skwentna River near Skwentna
46	15294350	Susitna River at Susitna Station
47	15294410	Capps Creek below North Capps Creek near Tyonek
48	15294450	Chuitna River near Tyonek
49	15294500	Chakachatna River near Tyonek
50	15283700	Moose Creek near Palmer
51	585750154101100	Kamishak River near Kamishak
52	15294700	Johnson River above Lateral Glacier near Tuxedni Bay
53	15266010	Kenai River below Russian River near Cooper Landing
54	15266020	Kenai River at Jims Landing near Cooper Landing
55	15266110	Kenai River below Skilak Lake outlet near Sterling
56	15267160	Swanson River near Kenai
57	631629149352000	Colorado Creek near Colorado
58	631018149323700	Costello Creek near Colorado
59	15273020	**Rabbit Creek at Hillside Drive near Anchorage**
60	15273030	**Rabbit Creek at East 140th Avenue near Anchorage**

Appendix 1. Cook Inlet Basin National Water-Quality Assessment site-numbering system—*Continued*

Site number	U.S. Geological Survey station	
	Number	Name
61	15273040	**Rabbit Creek at Porcupine Trail Road near Anchorage**
62	15273090	**Little Rabbit Creek at Nickleen Street near Anchorage**
63	15273097	**Little Rabbit Creek at Goldenview Drive near Anchorage**
64	15274395	**Campbell Creek at New Seward Highway near Anchorage**
65	15274557	**Campbell Creek at C Street near Anchorage**
66	15274796	**South Branch of South Fork Chester Creek at tank trail near Anchorage**
67	15274830	**South Branch of South Fork Chester Creek at Boniface Parkway near Anchorage**
68	15276200	**Ship Creek at Glenn Highway near Anchorage**
69	15273100	**Little Rabbit Creek near Anchorage**
70	15239070	Bradley River near tidewater near Homer
71	594507151290000	Beaver Creek 2 miles above mouth near Bald Mountain near Homer
72	594734151142900	Anchor River near Bald Mountain near Homer
73	15239840	Anchor River above Twitter Creek near Honmer
74	595126151391000	Chakok River 7.5 miles above mouth near Anchor Point
75	595506152403300	Stariski Creek 2 miles below unnamed tributary near Ninilchik
76	15240300	Stariski Creek near Anchor Point
77	600107151112800	North Fork Deep Creek 4 miles above mouth near Ninilchik
78	600047151383100	Deep Creek 0.4 mile above Clam Creek near Ninilchik
79	600204151401800	Deep Creek 0.6 mile above Sterling Highway near Ninilchik
80	600945151210900	Ninilchik River 1.5 miles below tributary 1 near Ninilchik
81	600321151325000	Ninilchik River below tributary 3 near Ninilchik
82	601100151000000	Nikolai Creek near Kasilof
83	613430150255000	Susitna River above Yentna River near Susitna Station
84	15281500	Camp Creek near Sheep Mountain Lodge
85	15292780	Susitna River at Sunshine
86	622302150083000	Susitna River 5 miles above Talkeetna River near Talkeetna
87	623705150005000	Susitna River at Curry
88	623850147225000	Oshetna River near Cantwell
89	623840147260000	Goose Creek near Cantwell
90	624658147562000	Kosina River near Cantwell
91	624953148151500	Watana Creek near Cantwell
92	625000149223500	Portage Creek near Gold Creek
93	624718149393600	Indian River near Gold Creek
94	15283550	Moose Creek above Wishbone Hill near Sutton
95	15292302	Camp Creek at mouth near Colorado
96	15292304	Costello Creek below Camp Creek near Colorado
97	625012150182700	Crystal Creek at mouth near Talkeetna
98	625014150183200	Coffee River above Crystal Creek near Talkeetna
99	623834150543300	Bear Creek near Talkeetna
100	623920150540300	Wildhorse Creek near Talkeetna
101	623510150450400	Long Creek near Talkeetna
102	623501151112900	Hidden Creek near Talkeeetna
103	623324151321600	Snowslide Creek at mouth near Talkeetna
104	623325151321800	Cripple Creek above Snowslide Creek near Talkeetna
105	622522151592200	Cascade Creek at mouth near Talkeetna
106	621936151582700	Fourth of July Creek at mouth near Talkeetna
107	621759152410500	Morris Creek at mouth near Talkeetna
108	621800152410600	Kichatna River above Morris Creek near Talkeetna
109	15294345	Yentna River near Susitna Station
110	600826152554400	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay
111	600803152552400	Kona Creek 2.5 miles above mouth above Lateral Glacier near Tuxedni Bay
112	600635152550900	Kona Creek tributary above Lateral Glacier near Tuxedni Bay
113	600636152551400	Kona Creek 0.8 mile above mouth above Lateral Glacier near Tuxedni Bay
114	600739152570701	Spring 1 near Johnson Glacier near Tuxedni Bay
115	600715152572800	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay
116	600713152574000	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay
117	600658152581400	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay
118	600609152561100	Johnson River tributary above Lateral Glacier near Tuxedni Bay

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Platyhelminthes														
Turbellaria	84	18	25	25	302	70	20	158	52	12	36	23	0	0
Nematoda	9	0	0	0	14	14	0	11	0	0	14	0	11	0
Cnidaria														
Hydridae														
Hydra sp.	0	0	0	0	0	0	0	0	0	0	0	0	11	0
Mollusca														
Gastropoda														
Hydrobiidae	0	0	0	0	0	0	0	11	0	4	0	0	0	4
Planorbidae	5	0	0	8	0	0	0	0	0	4	0	3	0	0
Valvatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Bivalvia														
Sphaeriidae	0	0	0	0	0	0	0	0	0	0	0	0	137	28
Annelida	0	0	109	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	0	0	0	34	0	0	2	0	2	0	0	1	2	8
Enchytraeidae	0	0	0	67	0	14	4	0	6	16	24	5	21	36
Lumbriculidae	79	84	0	512	58	29	20	53	0	20	0	0	0	0
Naididae	0	534	0	294	0	0	4	0	320	28	240	97	305	904
Tubificidae	5	0	0	34	0	0	0	0	2	76	66	4	63	208
Arthropoda														
Arachnida	14	36	269	76	158	112	24	42	12	72	72	25	126	48
Insecta														
Collembola	0	0	0	0	0	0	4	0	0	24	54	0	11	0
Ephemeroptera	0	0	8L	0	0	0	0	0	0	0	0	0	0	0
Ameletidae														
Ameletus sp.	0	12L	0	0	0	0	0	0	0	0	0	0	0	0
Baetidae	196L	84L	8L	622L	72L 14A	546L	228L	84L	16L	12L	12L	1L	1691L	28L
Acentrella sp.	5L	0	0	0	0	0	0	0	0	0	0	0	0	0
Acentrella turbida	0	0	168L	8L	0	0	0	0	0	0	0	1L	0	0
Baetis bicaudatus	5L	12L	25L	0	30L	14L	0	1L	0	4L	0	0	0	0
Baetis tricaudatus	0	0	0	18L	0	0	0	0	0	0	0	0	0	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Ephemeroptera—*Continued*														
Heptageniidae	140L 5A	186L	17L	8L	101L	392L	92L	168L	6L	8L	42L	0	0	0
Cinygmula sp.	5L	0	202L	0	158L	0	0	189L	0	4L	42L	0	0	0
Epeorus sp.	159L	3L	302L	0	763L	420L	308L	420L	2L	108L	222L	0	0	0
Ephemerellidae														
Drunella doddsi	93L	354L	386L	60L	202L	210L	60L	117L	18L	9L	78L	0	0	0
Ephemerella aurivillii	0	30L	1L	0	0	0	0	0	0	0	0	0	0	0
Plecoptera														
Taeniopterygidae														
Taenionema sp.	0	12L	0	8L	29L	0	12L	105L	32L	0	6L	3L	0	0
Nemouridae														
Zapada sp.	75L	24L	42L	17L	144L	420L	40L	263L	3L	0	48L	0	11L	0
Zapada cinctipes	9L	48L	8L	42L	43L	70L	28L	53L	2L	52L	42L	1L	210L 11A	24L
Leuctridae														
Despaxia augusta	5L	0	0	0	43L	57L	4L	0	0	0	0	0	0	0
Capniidae	5L	6L	0	17L	0	14L	4L	21L	4L	4L	0	3L	63L	0
Eucapnopsis brevicauda	0	18L	0	0	0	0	0	0	0	0	0	0	0	0
Perlodidae	5L	1A	8L	0	14L	0	0	32L	8L	4L	0	1L	53L	4L
Isoperla sp.	0	12L	1L	68L	0	84L	8L	0	0	0	0	0	0	1L
Chloroperlidae	0	102L	25L	34L	72L	84L	17L	42L	38L	0	12L	15L	0	16L
Suwallia sp.	44L	0	25L	0	187L	29L	44L	85L	0	40L	1L	0	0	0
Coleoptera														
Staphylinidae	0	0	0	0	14A	0	0	0	0	0	0	0	0	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Diptera														
Ceratopogonidae														
Ceratopogoninae	5L	6L	0	0	0	0	0	11L	0	0	0	0	0	0
Chironomidae	0	6P	42P 25L	0	14P 130A	0	4A	11L 21P	0	8P 24A	66P 6L	1P 4A	0	0
Tanypodinae														
Macropelopiini														
Macropelopia sp.	0	0	0	0	0	14L	0	0	0	0	0	0	0	0
Pentaneurini	0	0	0	0	0	0	0	0	0	0	0	1L	105L	16L
Diamesinae	0	0	0	8P	0	0	0	0	0	0	0	0	0	0
Diamesini														
Diamesa sp.	0	0	0	25L	0	0	0	0	0	0	0	0	0	0
Pagastia sp.	42L	318L	160L	185L	230L	140L	4L	63L	20L	12L	60L	109L	74L	16L
Potthastia sp.	0	0	0	25L	0	0	0	0	0	20L 12P	0	5L	32L	40L
Prodiamesinae														
Prodiamesa sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	4L
Orthocladiinae	23L 5P	30L	210L 59P	151L 25P	403L 101P	28L	0	85L 53P	2P 2L	0	120L 108P	0	420L	0
Corynoneura sp.	0	0	8L	0	0	0	0	11L	0	0	0	0	0	0
Thienemanniella sp.	0	0	25L	0	0	0	0	0	0	0	0	0	0	0
Brillia sp.	23L	0	0	17L	274L	140L	20L	420L	2L	36L	276L	6L	105L	0
Cricotopus sp.	0	0	0	0	0	0	0	0	0	0	0	0	11L	0
Eukiefferiella sp.	5L	0	50L	17L	130L	504L	4L	32L	0	4L	48L	0	32L	0
Heleniella sp.	9L	0	0	0	0	0	0	0	22L	0	6L	4L	0	0
Orthocladius sp.	0	0	8L	0	14L	14L	0	11L	0	0	6L	0	0	0
Parakiefferiella sp.	0	0	0	0	14L	14L	0	0	0	0	0	0	0	0
Paraphaenocladius sp.	5L	0	25L	0	0	0	0	0	0	0	0	0	0	0
Parorthocladius sp.	0	0	0	0	101L	0	0	0	0	0	12L	0	0	0
Rheocricotopus sp.	5L	6L	0	0	14L	14L	0	11L	0	0	0	0	0	0
Rheosmittia sp.	0	0	0	0	0	0	0	0	2L	0	0	0	0	0
Synorthocladius sp.	0	0	0	0	0	0	0	21L	0	0	0	0	0	0
Tvetenia sp.	5L	6L	17L	25L	72L	0	0	21L	0	24L	0	0	0	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Diptera—*Continued*														
Chironomidae—*Continued*														
Chironominae	0	0	25P	0	0	0	0	0	0	0	0	0	0	0
Chironomini	0	0	0	0	0	0	0	0	0	0	0	0	11L	0
Parachironomus sp.	0	0	0	0	0	0	0	147L	0	0	6L	0	0	0
Polypedilum sp.	0	6L	0	8L	0	0	0	0	0	4L	0	0	0	0
Tanytarsini	0	0	0	0	0	0	0	11L	0	0	0	0	0	0
Micropsectra sp.	65L	0	0	17L	144L	154L	16L	462L	0	60L	192L	0	0	0
Rheotanytarsus sp.	0	0	0	0	0	0	0	0	6L	0	0	11L	84L	0
Stempellina sp.	5L	0	25L	0	0	0	0	0	0	0	0	0	0	0
Psychodidae	5L	0	8L	0	14L	28L	0	0	2L	24L	48L	0	0	4L
Simuliidae	84L 5P	0	101L	0	0	840L	172L	0	2L	4L	6L 6P	0	0	0
Simulium sp.	0	6L	17L 34P	8L	1L	0	0	0	0	0	0	0	0	0
Tipulidae														
Tipula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1L
Dicranota sp.	6L	6L	0	25L	30L	14L	0	11L	6L	4L	0	9L	43L	4L
Hesperoconopa sp.	0	6L	0	0	0	0	0	0	14L	12L	6L	1L	0	0
Pedicia sp.	0	0	0	0	0	0	4L	0	0	0	0	1L	0	0
Empididae	0	0	0	34L	14P	0	0	0	0	0	0	0	0	0
Clinocera sp.	0	0	8L	0	0	28L	0	0	0	24L	6L	0	0	0
Oreogeton sp.	1L	0	0	0	43L	0	0	0	0		6L	0	0	0
Hemerodromiinae	23L	36L	8L	0	72L	14L	0	21L	2L	16L	12L	6L	32L	0
Stratiomyidae	0	0	0	0	0	0	0	0	0	0	6L	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	32L	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Trichoptera														
Hydropsychidae														
Ceratopsyche sp.	0	0	0	0	0	0	0	0	0	0	0	0	11L	4L
Rhyacophilidae														
Rhyacophila sp.	23L	0	0	0	15L	280L	24L	43L	0	44L	37L	0	0	0
Glossosomatidae	0	0	0	0	0	0	100L	0	0	0	0	0	0	0
Glossosoma sp.	271L	204L	168L	126L	43L	112L	0	42L	60L	380L	6L	52L 4P	33L 11P	0
Brachycentridae														
Brachycentrus sp.	0	42L	0	0	0	0	0	0	0	0	0	0	63L	0
Brachycentrus americanus	0	1L	8L	314L	0	0	0	0	4L	0	0	0	13L	0
Limnephilidae	23L	36L	0	84L	29L	98L	16L	63L	2L	108L	78L	6L	11L	8L
Apatania sp.	0	0	0	8L	0	0	0	0	0	0	0	0	11L	0
Ecclisomyia sp.	0	15L	9L	3L	45L	0	8L	63L	2L	0	6L	0	0	0
Ecclisocosmoecus scylla	1L	0	0	0	0	17L	4L	11L	0	0	0	0	0	0
Hesperophylax sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1L
Onocosmoecus unicolor	0	0	1L	1L	0	0	0	0	0	0	6P	0	0	0
Psychoglypha subborealis	0	0	1L	0	0	0	0	0	0	0	0	0	0	1P
Lepidoptera														
Pyralidae														
Crambus sp.	9L	0	0	0	0	0	4L	0	0	0	0	0	0	0

Appendix 3. Biological metrics calculated from macroinvertebrate data collected at 14 sites in Anchorage in 1999

[Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera]

Biological metric	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Margalef diversity index (lowest practical taxonomic level of identification)	5.42	4.52	5.19	4.73	4.65	3.99	4.32	4.78	4.76	5.01	5.06	4.33	3.87	3.17
Margalef's diversity index (family level)	3.12	2.58	2.28	2.87	2.39	2.35	3.07	2.33	3.22	3.2	2.73	2.83	2.54	2.21
Shannon diversity index	2.93	2.59	3.06	2.79	3.18	2.86	2.56	3.10	2.16	2.85	3.16	2.33	2.34	1.46
Hilsenhoff family-level biotic index	3.54	4.33	3.53	4.66	4.32	3.96	3.43	4.30	5.34	3.11	5.14	4.77	4.48	7.30
Percentage Chironomidae	12.0	16.1	25.2	16.4	37.6	20.3	3.7	39.4	8.3	15.4	44.3	35.0	22.6	5.4
Percentage Ephemeroptera	37.9	29.5	41.4	23.4	30.7	31.4	52.8	28.0	6.2	11.0	17.9	.5	43.8	2.0
Percentage Plecoptera	9.5	9.7	4.0	6.1	12.2	15.1	12.0	17.2	12.9	7.6	4.9	5.7	9.0	3.2
Percentage Trichoptera	19.8	12.9	6.9	17.5	3.0	10.1	11.7	6.3	10.1	40.3	6.0	15.4	4.0	1.0
Percentage Oligochaeta	5.2	26.8	4.0	30.8	1.3	.9	2.3	1.5	49.0	10.6	14.9	26.6	10.1	81.6
Percentage filterers	17.5	18.3	31.4	27.0	37.6	37.0	16.9	39.4	9.2	15.7	44.8	35.0	28.4	7.6
Percentage collectors	24.2	24.5	22.1	42.1	8.9	16.4	23.6	7.3	5.9	11.0	9.2	1.7	45.5	17.5
Percentage predators	5.4	5.2	2.5	3.3	7.9	10.0	7.1	6.1	6.8	8.5	3.3	4.0	2.2	1.5
Percentage scrapers	41.4	17.8	26.5	5.2	31.3	19.8	38.4	27.9	17.8	38.8	15.7	19.6	1.1	.0
Percentage shredders	8.0	5.9	2.3	5.6	7.7	13.4	8.0	13.3	4.3	13.3	8.4	4.5	7.4	2.5
Total taxa richness (lowest practical taxonomic level of identification)	41	36	42	39	40	35	32	40	32	37	40	27	33	24
Total taxa richness (family level)	24	21	19	24	21	21	23	20	22	24	22	18	22	17
Percentage two dominant taxa	29.1	38.5	25.5	37.1	25.7	27.5	41.1	25.2	56.5	36.9	23.3	51.1	53.1	78.5
Percentage EPT	67.2	52.1	52.4	47.0	45.9	56.6	76.5	51.5	29.3	58.8	28.9	21.6	56.8	6.1
EPT taxa richness	11	12	10	12	11	11	12	11	11	10	9	8	9	6
Ratio of EPT to Chironomidae abundances	85	76	68	74	55	74	95	57	78	79	39	38	71	53
Ratio of Baetidae to Ephemeroptera abundances	34	14	18	91	9	35	33	9	38	11	3	100	100	100

Appendix 4. Nutrient and major-Ion concentrations in water samples from 14 sites in Anchorage in 1999

[Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. E, estimated value. —, none]

Nutrient, major ion, or physical property	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Water temperature, in degrees Celsius	7.5	7	9.5	9.5	6	8.5	9.5	7.5	11.5	9.5	7.5	9	10	10
Discharge, in cubic feet per second	6.2	148	44	224	18	4.4	6.3	18	71	7	23	99	8.9	31
Specific conductance (laboratory), in microsiemens per centimeter at 25°C	109	156	76	169	68	87	116	60	103	136	86	111	217	242
Oxygen, dissolved, in milligrams per liter	11	11.8	11	10.7	12	11	11.1	12	10.2	11.8	11.6	10.5	10.2	11.3
Field pH, in standard units	7.7	7.5	7.7	7.6	7.4	7.8	7.6	7	7.9	7.9	7.6	7.4	7.3	7.7
Laboratory pH, in standard units	7.8	7.8	7.7	7.8	7.7	7.7	7.9	7.7	7.7	7.9	7.5	7.4	7.3	7.6
Ammonia as nitrogen, in milligrams per liter as N	.002	.003	.009	.004	<.002	.002	.003	.002	.004	<.002	.003	.005	.012	.024
Nitrite as nitrogen, in milligrams per liter as N	.001	<.001	.001	.002	<.001	<.001	.001	<.001	.001	.001	<.001	.001	<.001	.009
Ammonia as nitrogen plus organic nitrogen, in milligrams per liter as N	.14	E .10	<.10	E .10	E .10	.11	.11	E .10	E .10	.17	E .10	<.10	.18	.17
Ammonia plus organic nitrogen, in milligrams per liter as N	.23	E .09	E .07	E .09	E .09	.14	.19	E .09	.1	.15	.16	.14	.26	.22
Nitrite and nitrate, dissolved, in milligrams per liter as N	.412	.106	.064	.356	.282	.194	.437	.287	.098	.505	.318	.228	.462	.629
Total phosphorous, dissolved, in milligrams per liter as P	.022	<.004	<.004	.009	.004	.008	.008	<.004	.008	.009	.014	.012	.026	.022
Phosphorous, dissolved, in milligrams per liter as P	<.004	<.004	<.004	<.004	<.004	<.004	.005	<.004	<.004	<.004	<.004	<.004	.004	.008
Orthophosphorus, in milligrams per liter as P	.004	<.001	.001	<.001	<.001	.002	<.001	<.001	.002	.002	.001	<.001	<.001	.004
Organic carbon, dissolved, in milligrams per liter as C	1.9	.9	.9	1.3	.6	1.4	2.8	.8	1.2	3.1	1.4	1.9	3.9	4
Organic carbon, suspended, in milligrams per liter as C	.2	<.20	.2	<.20	—	—	<.20	<.20	.2	—	.2	<.20	—	.4
Calcium, dissolved, in milligrams per liter as Ca	17	24	13	25	9.6	12	17	11	14	20	12	16	25	29
Magnesium, dissolved, in milligrams per liter as Mg	3.2	3.4	1.7	3.9	1.6	2.1	2.9	1.9	2	3.3	2.1	2.7	5.3	6.8
Sodium, dissolved, in milligrams per liter as Na	1.7	2.2	1.1	2.6	1.2	1.5	2.1	1.4	1.3	2.7	1.9	1.8	5.9	7.5
Potassium, dissolved, in milligrams per liter as K	.21	.28	.21	.36	.15	.17	.32	.21	<.10	.35	.28	.32	.58	1.1
Chloride, dissolved, in milligrams per liter as Cl	.46	.34	.2	1.4	.33	.37	1.3	.96	<.10	2.8	2	1.7	9.6	15
Sulfate, dissolved, in milligrams per liter as SO_4	11	29	13	25	8.9	14	13	7.9	14	16	8.9	14	17	22
Fluoride, dissolved, in milligrams per liter as F	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
Silica, dissolved, in milligrams per liter as SiO_2	10	5.7	6	6.8	7.3	7.3	8.5	7.7	6	8.7	7.8	6.7	11	11
Iron, dissolved, in micrograms per liter as Fe	<10	<10	<10	E 7.5	<10	<10	13	<10	28	12	E 5.8	46	200	160
Manganese, dissolved, in micrograms per liter as Mn	<3.0	<3.0	<3.0	22	<3.0	3.9	3.4	<3.0	5.6	E 2.1	<3.0	16	70	67
Dissolved-solids residue at 180°C, in milligrams per liter	87	96	53	99	49	62	78	53	68	99	55	74	129	151
Specific conductance (field), in microsiemens per centimeter	129	164	87	177	74	96	124	82	101	151	93	120	206	251

Appendix 5. Trace-element concentrations in streambed sediments collected from 14 sites in Anchorage in 1999

[Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. <, below detection limit]

Trace element	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Aluminum, in percent	4.6	6.8	6.5	7.1	6.5	6.3	6.1	5.7	6.3	6.4	5.7	6.3	6.3	5.8
Antimony, in micrograms per gram	.6	1.2	1	1.2	1.4	1	1	1.2	.9	.9	1.2	1	1.4	2.4
Arsenic, in micrograms per gram	15	10	10	11	7.7	6.2	8.8	7.9	9.6	7.6	7.6	9.1	15	26
Barium, in micrograms per gram	410	660	720	650	650	670	660	600	610	670	580	610	550	600
Beryllium, in micrograms per gram	1	2	1	2	1	1	1	1	1	1	1	1	1	1
Bismuth, in micrograms per gram	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cadmium, in micrograms per gram	.2	.2	.2	.2	.2	.2	.3	.2	.2	.2	.2	.3	.7	1
Calcium, in percent	2.8	1.7	2.1	1.8	2	1.9	2	1.9	2	1.9	2	2	2.2	2
Cerium, in micrograms per gram	29	49	46	49	41	44	42	44	45	43	45	44	43	32
Cobalt, in micrograms per gram	14	19	21	20	18	15	16	16	17	15	16	18	20	20
Chromium, in micrograms per gram	81	95	110	110	72	62	63	85	99	64	91	110	110	120
Copper, in micrograms per gram	38	48	50	61	47	44	41	43	40	37	45	49	53	64
Europium, in micrograms per gram	<1	1	1	1	1	1	1	1	1	1	1	1	1	1
Gallium, in micrograms per gram	9	16	14	16	13	12	12	12	13	12	13	14	12	13
Gold, in micrograms per gram	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Holmium, in micrograms per gram	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron, in percent	3.5	4.2	4.2	4.4	3.9	3.5	3.8	3.4	4	3.6	3.5	4	4.9	5.9
Lanthanum, in micrograms per gram	14	24	22	24	20	22	21	23	21	21	23	22	20	18
Lead, in micrograms per gram	10	11	11	15	10	10	10	10	11	10	11	17	61	110
Lithium, in micrograms per gram	21	40	32	40	31	30	31	28	28	31	28	30	29	27
Magnesium, in percent	.9	1.2	1.2	1.4	1	.94	.96	.98	1.1	.99	1	1.2	1.1	1.2
Manganese, in micrograms per gram	1,300	870	970	1,300	1,000	1,200	1,500	1,100	860	1,300	1,100	970	1,400	2,600
Mercury, in micrograms per gram	.16	.18	.81	.16	.34	.21	.25	.29	.61	.22	.36	.33	.17	.17
Molybdenum, in micrograms per gram	2	1	2	1	1	3	2	1	1	2	1	1	1	2
Neodymium, in micrograms per gram	15	23	21	24	20	21	21	22	20	21	22	21	19	17
Nickel, in micrograms per gram	29	43	44	46	32	28	30	35	40	31	36	62	47	50
Niobium, in micrograms per gram	<4	6	6	7	5	6	6	6	6	6	6	6	5	8
Phosphorus, in percent	.22	.12	.14	.13	.16	.13	.14	.12	.13	.12	.12	.12	.18	.15
Scandium, in micrograms per gram	11	17	17	18	15	14	15	15	16	15	15	17	15	16
Selenium, in micrograms per gram	5.8	.9	2.2	.8	2.1	2.1	2.1	1.5	1.4	1.6	1.5	1.1	1.4	1.1
Silver, in micrograms per gram	.2	.2	.3	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.5
Sodium, in percent	1.2	1.7	1.6	1.8	1.6	1.8	1.7	1.7	1.8	1.8	1.7	1.7	1.8	1.6
Strontium, in micrograms per gram	270	270	240	270	240	270	250	250	250	260	250	240	240	250
Sulfur, in percent	.2	.06	.1	.06	.09	.1	.12	.06	.1	.08	.07	.1	.18	.2
Tantalum, in micrograms per gram	<1	1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Thorium, in micrograms per gram	2	4	4	4	3	3	3	4	4	4	4	4	4	3
Tin, in micrograms per gram	<1	1	1	2	<1	1	<1	<1	1	<1	<1	1	2	4
Titanium, in percent	.33	.43	.52	.47	.47	.48	.4	.36	.49	.41	.41	.4	.37	.39
Uranium, in micrograms per gram	2.4	1.6	2.1	1.6	1.5	1.5	1.5	1.4	1.7	1.4	1.5	1.7	1.4	1.3
Vanadium, in micrograms per gram	100	140	140	150	120	110	110	120	120	110	120	130	120	130
Ytterbium, in micrograms per gram	1	2	2	2	2	2	2	2	2	2	2	2	2	2
Yttrium, in micrograms per gram	15	20	20	22	20	18	19	20	19	19	20	20	18	20
Zinc, in micrograms per gram	82	100	100	120	110	110	140	110	92	160	120	180	420	590
Organic carbon, in percent	16	3.16	6.32	2.9	7.26	5.51	6.74	5.07	4.99	4.3	5.71	4.63	6.93	6.04
Inorganic carbon, in percent	.13	.02	.03	.02	.03	.03	.06	.02	.02	.03	.03	.02	.04	.05
Total, organic plus inorganic carbon, in percent	16.2	3.18	6.35	2.92	7.29	5.54	6.8	5.09	5.01	4.33	5.74	4.65	6.97	6.09

Hydrobiologia **501:** 117–131, 2003.

Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska*

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Received 26 March 2002; in revised form 22 April 2003; 19 May accepted

Key words: urbanization, impervious area, macroinvertebrates, thresholds, water quality

Abstract

We examined biotic and physiochemical responses in urbanized Anchorage, Alaska, to the percent of impervious area within stream basins, as determined by high-resolution IKONOS satellite imagery and aerial photography. Eighteen of the 86 variables examined, including riparian and instream habitat, macroinvertebrate communities, and water/sediment chemistry, were significantly correlated with percent impervious area. Variables related to channel condition, instream substrate, water chemistry, and residential and transportation right-of-way land uses were identified by principal components analysis as significant factors separating site groups. Detrended canonical correspondence analysis indicated that the macroinvertebrate communities responded to an urbanization gradient closely paralleling the percent of impervious area within the subbasin. A sliding regression analysis of variables significantly correlated with percent impervious area revealed 8 variables exhibiting threshold responses that correspond to a mean of 4.4 – 5.8% impervious area, much lower than mean values reported in other, similar investigations. As contributing factors to a subbasin's impervious area, storm drains and roads appeared to be important elements influencing the degradation of water quality with respect to the biota.

Introduction

Anchorage is unique with respect to urbanization effects on streams (Milner & Oswood, 2000), as it has a relatively large population (~260 000) and exhibits a steep urbanization gradient over short distances. This includes rapid changes from uninhabited wilderness along mountains in upper reaches of the basins to densely populated, urbanized areas near the mouths of streams draining the city. In most other regions, areas upstream from urban development have been disturbed by logging, mining, agriculture, or additional urbanization.

Numerous studies document the effects of nonpoint source contamination from urban runoff on water quality and stream biota (Klein, 1979; Sloane-Richey et al., 1981; Whiting & Clifford, 1983; Garie & McIntosh, 1986; Winter & Duthie, 1998; Paul & Meyer, 2001). Nonpoint source contaminants detrimental to water quality include salts from road deicing, pathogens from wildlife and pets, nutrients from fertilizer application to gardens, and oil and gasoline runoff from roadways. Urbanization can also alter the hydrologic characteristics of a stream by increasing the magnitude and frequency of peak discharges (Booth, 1991). As urbanization encroaches on riparian areas, the sources of woody debris to stream channels may be reduced or lost (Booth, 1991), resulting in increased channelization and decreased habitat complexity. Although riparian vegetation buffer zones typically improve local stream habitat conditions, watershed- or landscape-scale land use may be more important to biotic integrity (Roth et al., 1996).

In general, urbanization within a watershed may be characterized in terms of land cover changes or, more specifically, as the percentage of impervious area (PIA) (Arnold & Gibbons, 1996, Booth & Jackson, 1997; Wear et al., 1998; McMahon & Cuffney, 2000; Paul & Meyer, 2001). The percentage of impervious area at which degradation of water quality begins is varied, ranging from 4–5% (May et al., 1997) to 10–12% (Klein, 1979; Booth & Jackson, 1997; Wang et al., 2000). Land cover reported as total impervious area may be misleading in that the effective impervious area may be substantially less (Dinicola, 1989). Effective impervious area relates to the 'connectedness' of impervious area to a watercourse and intuitively has a greater effect on water quality than does impervious area separated from the watercourse. In other words, buffer areas and open space near water bodies are important in controlling runoff from impervious areas. In addition to buffer areas, the reduction of impervious area also must be considered. This was demonstrated in planned subdivisions where reduced individual lot sizes and increased open space resulted in a decrease in total impervious area for the subdivision from 17.5% to 10.7% (Arnold & Gibbons, 1996).

The goals of this study were (1) to determine those variables most closely related to the chosen urbanization surrogate, percent impervious area, within the boundaries of the Municipality of Anchorage, and (2) to characterize the nature of the biotic and physiochemical responses to urbanization as defined by percent impervious area.

Study area

The Municipality of Anchorage encompasses a large area (∼4900 km^2) north and west toward the top of the Knik Arm and south and east past the start of the Turnagain Arm, the majority of the land being undeveloped, remote, and mountainous terrain. Twelve sites in four stream basins (Chester, Campbell, Rabbit and Little Rabbit Creeks) were selected lying within the Municipality of Anchorage (Table 1; Fig. 1). Campbell Creek was considered a 4th-order stream near the mouth, whereas the other streams were 2nd order. All four basins lay immediately downslope of the western edge of the Chugach Mountains and proximal to the intersection of the Knik and Turnagain Arms of Cook Inlet.

The geology of the Anchorage area is primarily unconsolidated alluvium and glacial deposits, typical of the Cook Inlet-Susitna Lowlands physiographic region (Brabets et al., 1999). This lowland region is also the most developed and populated area in Alaska, accounting for more than 50% of the State's population. Climate in the Cook Inlet Basin in the vicinity of Anchorage is considered 'transitional' (between continental and maritime climates) and is characterized by annual precipitation of about 50 cm/yr. The mean annual temperature is approximately −3°C (Brabets et al., 1999).

The sites were selected on the basis of the degree of upstream urban development and density of roads as determined from U.S. Geological Survey (USGS) topographic maps (1:25 000 for developed areas and 1:63 360 for undeveloped, remote areas) and coverages based on geographic information system (GIS) source data of the area provided by the Municipality of Anchorage. The coverages included land use (residential, commercial, industrial, institutional, military, parks, vacant, waterbodies, and transportation right-of-ways), roads, sewers and storm drains, and census tracks. Three sites per basin were selected. Upstream sites were considered reference or low-impact sites, followed by intermediate sites with increasing amounts of impervious area. The downstream-most sites were the most urbanized, that is, comprised the greatest percentage of impervious area, within each basin. The increasing urbanization in a downstream direction presented a potential problem with observed impacts being confounded by natural downstream changes. However, this was considered when reaching practical conclusions regarding urban impacts related to impervious area.

Methods and materials

Macroinvertebrate, water-chemistry, and habitat data were collected during the summer low-flow period (June/July) in 2000. Sediment-chemistry data were collected the previous summer during site reconnaissance. All data represent an instantaneous sampling regime: only one sample was collected and used for each parameter or constituent in the subsequent analyses in this paper. While this presents limitations, such as identifying variation in biological communities and chemical constituents, this project was designed as a synoptic study and the one-time sampling efforts were utilized to identify potentially problematic stream conditions related to urbanization in the Anchorage area.

Table 1. Description of urban synoptic sites. Map ID's correspond to site locations on Figure 1.Sites are ordered from least to greatest percent impervious area [Dishcharge, Conductivity, pH, Water Temperature, and Dissolved Oxygen Concentration measured at time of collection of macroinvertebrate samples]

Site ID	USGS Station ID	Description	Elevation (m)	Subbasin Area (km^2)	Discharge (m^3/s)	Conductivity ($\mu S/cm$)	pH	Water Temperature (°C)	Dissolved Oxygen Concentration (mg/l)	Subbasin Road Density (km/km^2)	Subbasin Population Density ($no./km^2$)	Subbasin Storm Drainage Density (km storm $sewers/km^2$)	Subbasin Percent Impervious Area
CH1	15274796	South Branch Of South Fork Chester Creek at Tank Trail	109	11	0.10	117	8.2	4.5	11.4	0	0	0	0
C1	15274000	South Fork Campbell Creek near Anchorage	71	76	1.64	72	7.7	4	12.7	0.2	4	0	0.3
R1	15273020	Rabbit Creek at Hillside Drive	267	25	0.85	86	7.3	3.5	12.2	0.6	12	0	0.4
LR1 Street	15273090	Little Rabbit Creek at Nickleen	375	7	0.18	109	7.7	1	12.6	1.0	23	0	1.2
LR2	15273097	Little Rabbit Creek at Goldenview Drive	180	8	0.42	128	7.9	2.5	12.8	3.5	70	0	3.4
C2	15274395	Campbell Creek at New Seward Highway	30	43	2.21	84	7.6	5	11.6	1.0	180	0.77	3.7
R2	15273030	Rabbit Creek at East 140th Avenue	133	4	0.79	90	7.6	6	12.5	6.4	323	0	7.5
R3	15273040	Rabbit Creek at Porcupine Trail	37	5	0.96	96	7.6	6	12.2	7.3	378	0	8.1
LR3	15273100	Little Rabbit Creek near Anchorage	28	2	0.42	137	7.9	3	12.4	5.7	222	0.74	8.5
CH2	15274830	South Branch of South Fork Chester Creek at Boniface Parkway	60	27	0.34	162	7.7	8	11.7	3.5	665	2.82	10.6
C3	15274557	Campbell Creek at C Street	16	51	2.52	92	7.9	8	8.9	6.1	690	2.61	20.6
CH3	15275100	Chester Creek at Arctic Blvd	5	32	0.88	265	8.1	11.5	10.4	9.4	1747	7.05	39.9

Instream habitat

Reaches 90–150 m in length were chosen according to a combination of factors including representative habitat features for the immediate upstream and downstream area, the repetition of geomorphic channel units (pool, riffle, run) within the reach, meander frequency, and location of obstructions that would limit reach length (such as culverts) (Fitzpatrick et al., 1998). Channel, bank, and riparian characteristics (for example, bankfull channel width, bank vegetative cover) were recorded at each of 11 equidistant transects delineating the reach. Water depth, current velocity, and substrate particle size were also measured. Each stream reach was surveyed using total station equipment that was georeferenced with a survey-grade global-positioning system (GPS). The variables collected were used in metric calculations and subsequent correlation analyses.

Macroinvertebrates

Semiquantitative macroinvertebrate samples were collected during June/July of 2000 from five riffle locations within each reach using a 0.5-m-wide rectangular net with 425-μm mesh. Large particles were brushed by hand to dislodge macroinvertebrates, and finer grained sediments were disturbed to a depth of 10 cm within a 0.25-m^2 area in front of the net opening for 1 min (Cuffney et al., 1993). The five samples collected from each reach were composited into a single sample and elutriated onsite. Organisms were identified to the lowest practical taxonomic level (usually genus) at the Biological Unit of the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado (Moulton et al., 2000).

Ambiguous taxa were removed where low-level identification of damaged or immature specimens was not possible or because the lack of appropriate keys prevented a finer level of identification. In most cases, the higher level taxa abundances were proportioned among the lower levels relative to the abundances of the lower levels. In cases where lower level abundances were lower than or equal to the higher level abundances, lower level abundances were combined with higher-level abundances. Terrestrial macroinvertebrates were removed.

Water and sediment chemistry

Water-chemistry sampling (major ions, nutrients, and field parameters – pH, dissolved oxygen, specific conductance, and temperature) was performed as described by Shelton (1994). Stream water was collected with a handheld, depth-integrating sampler using the equal-width-increment sampling method. Water samples were collected at the same cross section as the discharge measurement. Samples were processed in the field, then shipped to and analyzed by the NWQL before being used in analyses.

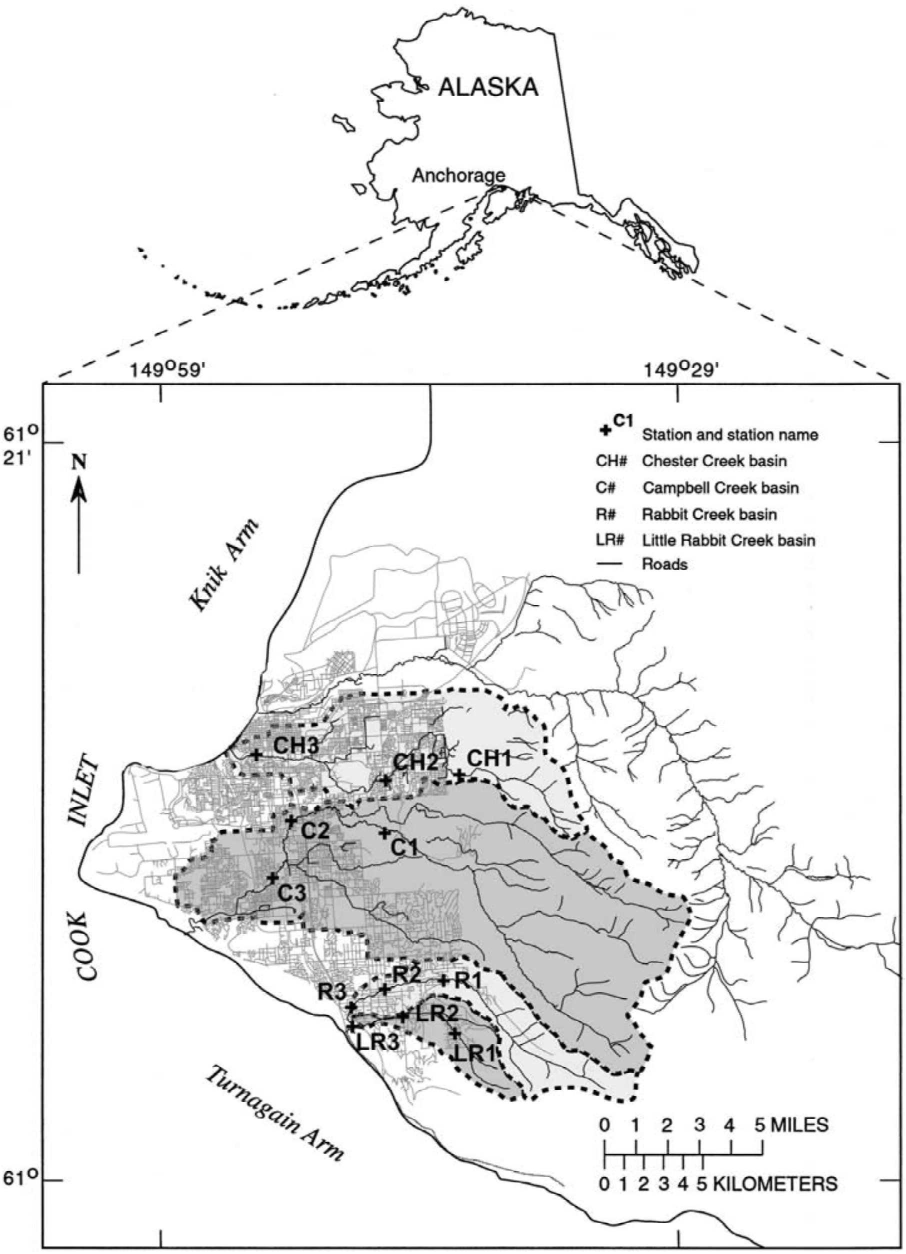

Figure 1. Basins, sites and roads in the Municipality of Anchorage.

Streambed sediments were sampled for trace elements as described by Shelton & Capel (1994). Fine-grained materials were collected from depositional areas of study reaches and wet-sieved in the field to less than 63 μm. Sieved sediments were sent to the NWQL for analysis of trace elements and major metals, such as aluminum and iron. The samples were dried, subjected to complete strong-acid digestion, and analyzed by atomic spectroscopy. Major constituents measured included aluminum, arsenic, cadmium, iron, lead, manganese, nickel, organic carbon, selenium, and zinc (Shelton & Capel, 1994).

Geographic characterization

Spatial data were determined from USGS 1:25 000 and 1:63 360 topographic maps, source data, land-use coverages (Municipality of Anchorage), satellite imagery (IKONOS 4-m multispectral images), and aerial photography (1-m grayscale Digital Orthorectified Quarter Quads [DOQQ]) and were entered into a GIS database. Subbasins were delineated from USGS maps and basin coverages were defined as the catchment area from a reach to the next reach upstream, or to the source from the furthest upstream reaches (Fig. 1). This strategy of creating incremental subbasins instead of cumulative subbasins reduces autocorrelation between sites within a basin. Associated spatial data were fit into each of the respective subbasins for future analysis.

Impervious area

Multispectral IKONOS satellite imagery with a resolution of 4 m and red and near-infrared bands generated a modified normalized difference vegetation index (NDVI), which was then used to isolate impervious areas. NDVI is a mathematical classification technique to determine pixel illumination condition (Deering et al., 1975). Values <0.32 were delineated as impervious areas. Verification involved a visual inspection of the imagery and groundtruthing, as well as inspection of 1-m grayscale panchromatic IKONOS imagery and USGS DOQQs.

Data analysis

Correlations and multivariate analysis

Spearman rank correlation analysis was used to identify response variables related to percent impervious area (PIA) (Statsoft Inc., 2001). Variables significantly correlated ($P < 0.05$) with impervious area were retained for additional analyses. Habitat, water and sediment chemistry variables, as well as land-use types were analyzed using principal components analysis (PCA) to reduce the number of variables in a detrended canonical correspondence analysis (DCCA). All variables used in the correlation analysis, except macroinvertebrate metrics, were grouped according to type and were used in PCA. Variables were separated into four groups; (1) variables associated with riparian and geomorphic characteristics (channel condition factors), (2) variables associated with instream cover and sediment characteristics (instream habitat factors), (3) land-use types, and (4) water- and sediment-chemistry (chemical factors). The first component PCA site scores were calculated for each of the four groups for use as environmental variables in the DCCA.

A direct gradient analysis (DCCA) using the abundance of macroinvertebrate taxa at all 12 sites was performed using the Multivariate Statistical Package (MVSP, 1999). Direct gradient analysis methods allow species data to be related directly to environmental data. DCCA assumes that the species exhibit distributions with a single mode along environmental gradients based on environmental variables.

The macroinvertebrate community was described relative to a gradient of urbanization by using a Spearman correlation of the first DCCA axis score against macroinvertebrate metric calculations. The macroinvertebrate metrics that were used are listed in appendix 1. Functional feeding group classifications followed those outlined by the U. S. Environmental Protection Agency (Barbour et al., 1999). This technique provided greater insight into the groups of macroinvertebrates driving the gradient with respect to biological properties, such as tolerance to perturbation, feeding ecology, and taxonomic diversity.

Determination of threshold response

A sliding regression was performed on each of the correlated variables with respect to PIA. The technique is based on a modification of linear regression comparison as described by Zar (1996). The PIA values were arcsine transformed to normalize the data. Response variables were either arcsine or log transformed to generate a more normal distribution. Beginning with the four sites containing the lowest PIA (group 1 – CH1, C1, R1, LR1), a regression line was fit to the points (subbasins). A regression line then was fit to the remaining eight sites (group 2 – LR2, C2, R2, R3, LR3, CH2, C3, CH3), and the slopes of the two lines were tested for significant differences. This procedure was repeated with the exception that the lowest PIA site within group 2 was moved into group 1 and the comparison of slopes was performed again. This process was repeated until a significant difference in slopes was noted or until all but the four highest PIA sites were left within group 2. If no significant difference in slope was identified, the variable was considered to exhibit a linear response. Variables with significantly different slopes were con-

Table 2. Significant ($P < 0.05$) Spearman correlations (r_s) between physical habitat, macroinvertebrate metrics, water and sediment chemistry variables, and subbasin percent impervious area (PIA)

PIA vs Variable	Spearman r_s	P-level
Channel Condition		
Sinuosity	–0.844	0.0006
Percent Bank Erosion	–0.671	0.0168
Instream Habitat		
Percent Reach >20% Embedded	0.587	0.0448
Macroinvertebrate Metrics		
EPT Abundance	–0.734	0.0065
Percent EPT	–0.587	0.0446
EPT Family Txa Richness	–0.740	0.0059
Hilsenhoff Family-Level Biotic Index	0.748	0.0051
Percent Shredders	–0.608	0.0358
Total Family Richness	–0.651	0.0218
Water Chemistry		
Sodium	0.610	0.0351
Chloride	0.788	0.0023
Iron	0.732	0.0068
Manganese	0.800	0.0018
Sediment Chemistry Selenium	–0.913	<0.0001
Cadmium	0.659	0.0198
Zinc	0.866	0.0003
Lead	0.651	0.0219
Nickel	0.650	0.022

sidered to exhibit a threshold response if the slope of the regression of the greatest number of sites differed significantly from the slope of the regression of all sites. The threshold values were derived by determining the range between the highest PIA site in group 1 and the lowest PIA site in group 2.

Results

Water-chemistry response

Four water chemistry variables of 17 analyzed were significantly correlated with PIA; sodium, chloride, iron, and manganese (Table 2). Sodium concentrations were typically high in downstream subbasins, with the exception of the Campbell Creek Basin. Concentrations were found at CH3 (7.3 mg/l, Table 3) exceeding mean concentrations for the Cook Inlet Basin. Chloride was also high at CH3. Iron was highest at CH2 (130 μg/l), and the next-highest concentration was at CH3 (70 μg/l) (reddish-brown sediments from oxidized iron were observed upstream from the sample point at CH2). Iron concentrations did not exceed mean concentrations for the Cook Inlet Basin.

Water-chemistry variables did not show a significant threshold response, although both sodium and iron exhibited breaks during the first iteration of the sliding regression (7.5–8.1% and 8.5–10.7%, respectively). Chloride (Fig. 3A) and manganese displayed the highest coefficients of determination (0.72 and 0.70, respectively) of the four water-chemistry variables, exhibiting strong linear responses to increasing PIA.

Magnesium had the highest PCA loading of all chemical variables (water and sediment). Specific conductance, calcium, manganese, sulfate, potassium, sodium, and chloride also showed high relative loadings on the first component, which accounted for 46% of the variance. Dissolved oxygen was the only constituent of water or sediment chemistry that loaded negatively on the first component. Water chemistry appears to have greater relative importance (explains more of the variance) with respect to the first component than sediment chemistry has. Site scores are shown in Table 4.

Sediment-chemistry response

Five of the 19 sediment-chemistry variables were significantly correlated with PIA: selenium, cadmium, zinc, lead, and nickel (Table 2). Selenium, the most highly correlated sediment-chemistry variable (r_s = -0.913, $P < 0.01$), was negatively correlated with PIA, whereas the remaining trace elements were positively correlated with PIA. Concentrations of selenium were highest at the upstream subbasins (5.8–2.1 μg/g), with CH1 concentrations more than double the next highest value (Table 3).

Cadmium concentrations were highest at CH2 and CH3 (0.7 and 1.0 μg/g, respectively). Concentrations in all other subbasins were relatively stable at 0.2–0.3 μg/g and were comparable to the mean concentrations at other sites throughout the Cook Inlet Basin (Frenzel, 2000). Concentrations of zinc and lead were high at CH2 and CH3 (Table 3) and exceeded the Cook Inlet Basin mean concentrations. Nickel concentrations significantly increased with increasing PIA, though no exceptionally high concentrations were noted.

Table 3. Variables and metrics significantly correlated with percent impervious area (PIA). Sites are arranged from lowest to highest PIA [CIB mean values = Cook Inlet Basin mean values as determined from Glass (1999) and Frenzel (2000)]

Sites		Habitat		Macroinvertebrate Metrics				Water Chemistry				Sediment Chemistry				
	Sinuosity	Percent Bank Erosion	>20 Percent Embedded	Hilsenhoff Family-Level Biotic Index	Percent Shredders	Total Taxa Richness (family)	EPT Taxa Richness (family)	Sodium (mg/l)	Chloride (mg/l)	Iron (μg/l)	Manganese (μg/l)	Selenium (μg/g)	Cadmium (μg/g)	Zinc (μg/g)	Lead (μg/g)	Nickel (μg/g)
CH1	1.47	77	6	3.74	6.4	18	8	1.8	0.7	10	1	5.8	0.2	82	10	29
C1	1.99	50	0	4.19	4.7	20	10	1	0.2	5	1	2.2	0.2	100	11	44
R1	1.9	50	6	3.75	6.1	17	8	1.3	0.4	5	1	2.1	0.2	110	10	32
LR1	1.19	32	45	3.83	8.2	22	11	1.7	0.7	10	2	2.1	0.2	110	10	28
LR2	1.36	45	64	3.51	2.5	19	7	2.2	2.2	20	5	2.1	0.3	140	10	30
C2	1.32	59	61	3.6	3.9	18	9	1.3	0.6	30	5	1.4	0.2	92	11	40
R2	1.34	32	12	4.02	4.9	17	7	1.7	1.1	5	1	1.5	0.2	110	10	35
R3	1.21	36	0	4.26	6.5	19	9	2.1	1.7	10	2	1.5	0.2	120	11	36
LR3	1.21	14	18	5.59	5.5	18	7	2.9	3.4	20	3	1.6	0.2	160	10	31
CH2	1.01	0	55	5.55	1.3	16	5	2.5	2.6	130	30	1.4	0.7	420	61	47
C3	1.09	23	76	5.13	0.4	16	5	1.7	1.4	50	14	1.1	0.3	180	17	62
CH3	1.03	45	64	7.68	0	12	4	7.3	15	70	62	1.1	1	590	110	50
CIB mean values								4.7	4.2	200	41	0.6	0.4	140	18	49

Table 4. PCA site scores for each of the four groups of variables analyzed. Each group represents a reduction of related variables, expressed as a single surrogate environmental variable

Sites	Channel Condition	Instream Habitat	Chemical Factors	Land-Use Factors
CH1	–0.116	0.098	0.111	–0.54
C1	0.518	–0.609	–0.747	–0.413
R1	–0.202	–0.71	–0.988	–0.341
LR1	–0.598	–0.324	–0.541	–0.542
LR2	–0.469	1	–0.06	–0.408
C2	1.195	0.612	–0.71	–0.081
R2	–0.358	–0.856	–0.766	–0.269
R3	–0.284	–0.844	–0.648	–0.158
LR3	–0.449	–0.594	–0.07	–0.173
CH2	–0.184	0.896	1.081	–0.107
C3	0.996	0.331	–0.112	1.707
CH3C	–0.048	1	3.451	1.325
Percent of total variance explained by component 1				
	37.7	33.7	45.7	65

Table 5. Ranges of incremental percent impervious area (PIA) thresholds as determined through sliding regression. r^2 and P values were calculated from regressions of all sites

	PIA	r^2	P
Selenium (Sediments)	3.4–3.7	0.6307	0.0020
Cadmium (Sediments)	7.5–8.1	0.5529	0.0056
Zinc (Sediments)	7.5–8.1	0.7417	0.0003
Lead (Sediments)	7.5–8.1	0.5826	0.0039
Nickel (Sediments)	No Break	0.3730	0.0349
Sodium	No Break	0.6164	0.0025
Chloride	No Break	0.7236	0.0005
Iron	No Break	0.4868	0.0117
Manganese	No Break	0.7006	0.0007
Percent of Reach >20% Embedded	3.4–3.7	0.3170	0.0566
Percent Bank Erosion	1.2–3.4	0.2017	0.1430
Stream Sinuosity	No Break	0.5016	0.0100
Hilsenhoff Family-Level Biotic Index	3.7–7.5	0.7266	0.0004
Percent Shredders	No Break	0.5599	0.0051
Total Taxa Richness (family level)	1.2–3.4	0.5998	0.0031
EPT Taxa Richness (family level)	No Break	0.6133	0.0026
Mean = 4.4–5.8			

Four sediment-chemistry variables showed a threshold response with respect to PIA (Table 5). The threshold for selenium was between 3.4 and 3.7 PIA. Thresholds for cadmium, zinc (Fig. 3B), and lead were between 7.5 and 8.1 PIA. Nickel exhibited a linear response (no breakpoint) characterized by a relatively weak straight-line association (r^2 = 0.373, Table 5).

PCA was used on a combination of all sediment- and water-chemistry data. Lead concentration had the highest loadings (relative importance) of all the sediment chemistry constituents on the first component. Cadmium, zinc, manganese, and arsenic also were highly loaded on the first component and accounted for the largest proportion of the variance explained by sediment chemistry in the newly created environmental variable, chemical factors. The first component accounted for about 46% of the variance (Table 4).

Physical response

Two channel condition metrics, sinuosity and percent bank erosion, exhibited significant negative correlations with PIA (Table 2). Sinuosity decreased with increasing PIA; CH2 showed the lowest value (1.01, or nearly straight) and all other downstream reaches displayed low values (range – 1.03–1.21) (Table 3). No threshold response was observed for sinuosity. Percent bank erosion values also decreased with increasing PIA [threshold response ranging from 1.2 to 3.4 PIA (Table 5)]. Percent bank erosion values were highest at upstream reaches and decreased downstream.

One instream habitat metric, percent reach >20% embedded, was significantly correlated with PIA (Table 2), with a threshold response from 3.4 to 3.7 (Table 5). This range generally related to road density values >1.8 km/km^2. Embeddedness was highest in subbasins with storm drains, except for LR1 and LR2 subbasins, which were undergoing substantial residential development during the study.

PCA showed that the new variable, instream habitat, was dominated on the first component by positive loadings of percent habitat abundance, >20% embeddedness, and by negative loadings of percent dominant large and small cobbles. The first component explained about 34% of the variance (Table 4). The other new physical response variable, channel condition, was dominated by positive loadings of run length and average bankfull width and by negative loadings of shade and riffle length on the first component. The first component explained approximately 38% of the variance. Table 4 shows the site scores for both new physical response variables.

Biotic response

Six biotic metrics were significantly correlated with PIA. Percent of EPT taxa and EPT relative abundance ($P = 0.05$ and 0.01 , respectively) were considered redundant and removed from further analyses, as both were less significant when compared with EPT taxa richness (family level) ($P = 0.01$). The three other macroinvertebrate metrics were Hilsenhoff FBI, percent shredders, and total family richness (Table 2).

Percent shredders, total family richness, and EPT taxa richness decreased with increasing PIA. Percent shredders was generally lower at all sites within the Campbell Creek Basin (C1, C2, and C3) compared to other basins, except LR2 and CH2 (Table 3), but no threshold response was apparent. Percent shredders showed the lowest correlation with PIA of the macroinvertebrate metrics (Table 5). Total taxa richness (family level) was generally highest at the upstream sites (CH1, C1, R1, LR1). A threshold response between 1.2 and 3.4 PIA separated the upstream sites from the middle and downstream sites (Table 5, Fig. 3C). EPT taxa richness was highest at LR1 and C1 and showed a linear response to PIA.

Conversely, FBI values increased with increasing PIA (Table 3, Fig. 3D). This was expected, as the metric measures the tolerances of invertebrates to perturbation, and the higher the value for a site, the greater the probability of organic pollution (Hilsenhoff, 1988). According to this index, the upstream subbasins ranged from excellent (organic pollution unlikely) for CH1 and R1 to very good (possible slight organic pollution) for LR1 and C1. Water quality in two middle subbasins, LR2 and C2 was rated as excellent, but was rated as very good at R2 and as fair at CH2. As in the upper subbasins, water quality was higher in subbasins with lower PIA. Water quality in only one of the downstream subbasins, R3, was rated as good (some organic pollution probable). Water quality at LR3 and C3 was rated as fair and, at CH3, was rated very poor (severe organic pollution likely).

Land use

PCA of land-use variables showed residential, transportation right-of-way, and institutional land uses as having the highest positive variable loadings. None of the variables were negatively loaded. The first component explained 65% of the variance. The site scores on the first component of the PCA (Table 4) were used as the new land-use environmental variable in the DCCA.

Direct gradient analysis

DCCA incorporated the four new variables created from the first component site scores derived from the PCA as environmental variables. It was necessary to minimize the number of environmental variables because the number of sampling sites was relatively small. The DCCA biplot was based on 57 macroinvertebrate taxa from the 12 sites (Fig. 2). The environmental variables are represented as vectors: the length relates to relative importance, and the direction relates to approximate correlation with the axes. The first axis accounted for 30.8% of the variance in the macroinvertebrate data and was correlated with land-use and chemical factors ($r = 0.80$ and 0.69, respectively), whereas the second axis accounted for

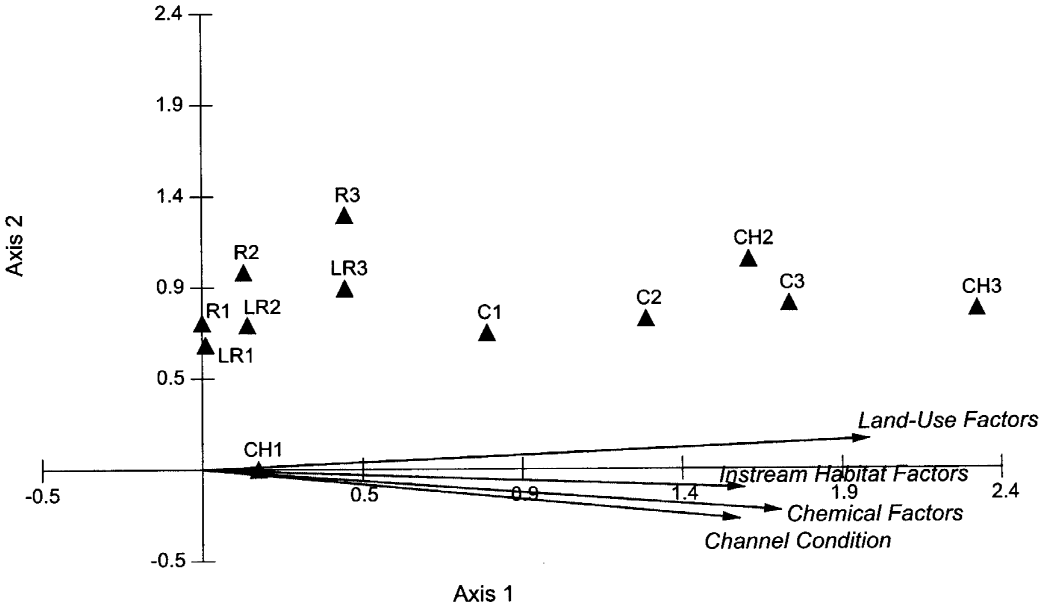

Figure 2. Detrended canonical correspondence analysis (DCCA) of the 12 study sites and relative abundance of macroinvertebrate taxa. Length of vectors indicates the relative importance of that environmental variable.

6.9% of the variance and was correlated with land use and channel condition ($r = 0.69$ and -0.08, respectively). The alignment of the sites along the first axis represents the gradient of urbanization as described by the macroinvertebrate species composition with respect to the environmental variables. According to the results of threshold responses, the split between urban affected and unaffected occurs near LR3 and R3.

The macroinvertebrate community was analyzed further by correlating the macroinvertebrate metrics with the first DCCA axis with macroinvertebrate metrics (Table 6). Positively correlated metrics (Hilsenhoff FBI and percent Oligochaeta) were related to measures of disturbance-tolerant macroinvertebrates found in areas of high PIA, whereas negatively correlated metrics (such as, percent EPT, percent shredders, and percent scrapers) were related to measures of intolerant macroinvertebrates in areas of low PIA. The second axis scores showed a marginal correlation with only the Hilsenhoff family-level biotic index ($r = 0.59$, $P = 0.04$).

Discussion

Streams in Anchorage, Alaska, showed effects from urbanization comparable to other studies (Klein, 1979; Sloane-Richey et al., 1981; Whiting & Clifford, 1983; Garie & McIntosh, 1986; Waters, 1995; May et al., 1997; Winter & Duthie, 1998; Wang et al., 2000). The gradient of urbanization, as expressed by PIA, was reflected by a shift in the macroinvertebrate community from intolerant organisms at sites with low PIA to tolerant organisms at sites with high PIA. Relatively few physiochemical variables or biotic metrics were significantly correlated with PIA, but the threshold-type responses typically occurred at PIA values lower than 10%. These values are lower than those generally observed elsewhere (Klein, 1979; Booth & Jackson, 1997; Wang et al., 2000). Some variables, such as reach >20% embedded and bank erosion, had thresholds occur at lower than 5 PIA.

The Cook Inlet Basin contains mineralized rock and soils over a wide area, especially when compared with other U.S. Geological Survey National Water-Quality Assessment Program (NAWQA) study units with respect to trace elements in streambed sediments (Brabets et al., 1999; Frenzel, 2000). Selenium concentrations for all sites in the basin exceeded the national background level (0.7 μg/g) for NAWQA study units (Gilliom et al., 1998), and concentrations were elevated even in undeveloped subbasins (Table 3). The extremely high concentration of selenium (5.8 μg/g) at CH1 may be attributable to a now-defunct

Table 6. Spearman rank order correlations between site scores from DCCA axis one and macroinvertebrate metrics. Bolded correlations are significant at $P < 0.05$

Macroinvertebrate metrics	Spearman r	P-level
Shannon-Weiner Diversity Index	0.143608	0.656129
Total Abundance	0.038529	0.905370
EPT Abundance	**–0.781087**	**0.002705**
Hilsenhoff Family-level Biotic Index	**0.591945**	**0.042590**
Percent Chironomidae	0.273205	0.390234
Percent Ephemeroptera	**–0.863158**	**0.000299**
Percent Plecoptera	–0.532400	0.074756
Percent Trichoptera	–0.568421	0.053808
Percent Oligochaeta	**0.788092**	**0.002329**
Percent Filterers	0.308232	0.329698
Percent Collectors	–0.119298	0.711915
Percent Predators	–0.101576	0.753434
Percent Scrapers	**–0.818042**	**0.001147**
Percent Shredders	**–0.746061**	**0.005329**
Total Taxa Richness (lowest practical taxonomic identification)	–0.070673	0.827231
Total Taxa Richness (family-level identification)	–0.491163	0.104899
Percent Dominant Taxa - 2	–0.230229	0.471601
Percent EPT	**–0.907182**	**0.000046**
EPT Taxa Richness (family-level)	–0.501801	0.096459
Ratio of EPT to Chironomidae	**–0.838596**	**0.000654**
Ratio of Baetidae to Ephemeroptera	0.414035	0.180880

coal-burning power generation plant nearby. The concentration at CH1 is considered a 'high hazard level' (>4 μg/g) as described by Lemly (1995), and selenium enters the food web most readily from benthic sources (Baines et al., 2002), although the biota at this site did not appear to be adversely affected during the sampling period.

Cadmium, zinc, and lead concentrations all exhibited a threshold response between 7.5 and 8.1 PIA. Cadmium concentrations were below the national median concentration (0.4 μg/g) at all sites except CH2 and CH3, two highly urbanized subbasins. None of these trace element concentrations exceeded the probable effect level (PEL) of 3.5 μg/g recommended by the Canadian Council of Ministers of the Environment (1999) and, therefore, probably had little effect on biota, even at the downstream sites. Zinc (Fig. 3B) and lead often are cited as good indicators of urbanization (Klein, 1979; Porcella & Sorensen, 1980; May et al., 1997). Zinc concentrations exceeded the PEL of 315 μg/g at CH2 and CH3, and concentrations at all sites except CH1 and C2 exceeded the national median concentration. The elevated levels of zinc (and lead) in subbasins where PIA is high are generally attributed to construction and transportation (May et al., 1997), and road sediment is a primary high-concentration source for these metals (Sutherland, 2000; Sutherland & Tolosa, 2001; Turer et al., 2001). Lead concentrations were generally below the national median concentration (24.3 μg/g) except at CH2 and CH3. Lead exceeded the PEL of 91.3 μg/g at CH3. Lead and zinc are both known to adversely affect stream organisms (Garie & McIntosh, 1986; Besser et al., 2001) and may be more of a problem during times of high flow (May et al., 1997). Storm drains and roads are probably the primary mechanisms for the transportation of zinc and lead in Anchorage, moving them toward eventual downstream deposition in the sediments. Concentrations of contaminants generally were highest in subbasins with storm drains and high PIA (Tables 1 and 4). Nickel was the only significantly correlated trace element not showing a threshold response. Although all concentrations exceeded the 25 μg/g national median, none exceeded concentrations measured elsewhere in the Cook Inlet Basin (Frenzel, 2000) and are probably naturally occurring.

Water quality related to water chemistry generally declined with increasing PIA. Sodium, chloride, iron, and manganese were significantly correlated with PIA, although no threshold responses were observed. Sodium and chloride commonly are associated with the application of deicing salts (Koryak et al., 2001) and with domestic sewage and may be considered more of a stress factor in low flow conditions because high flows often have the effect of diluting soluble forms (Klein, 1979; May et al., 1997). Because concentrations of both constituents were greater than mean concentrations for the Cook Inlet Basin (Table 3), increased PIA related to urbanization appears to be a probable factor. Conversely, manganese and iron probably are not related directly to PIA in this case, because concentrations of neither constituent exceeded the mean concentrations measured for the Cook Inlet Basin.

The three physical response variables appear to be questionable in their efficacy in accurately describing changes related to PIA. Sinuosity exhibited the best fit of the sites to the regression curve of the three variables, but only marginally (r^2 = 0.5016). Sinuosity generally is used at the stream segment rather than the stream reach level (Fitzpatrick et al., 1998). Reach lengths of 90–150 m, while adequate for most

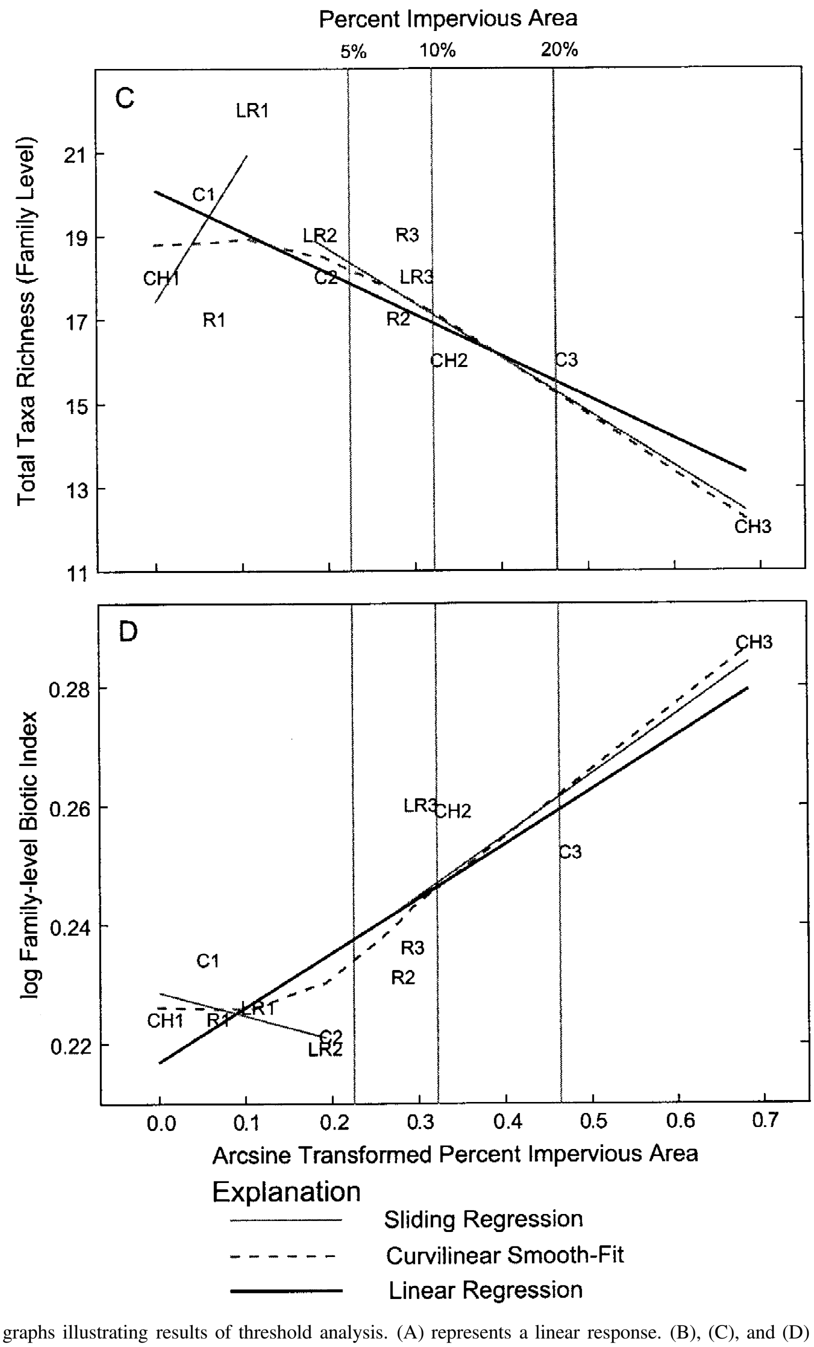

Figure 3. Selected graphs illustrating results of threshold analysis. (A) represents a linear response. (B), (C), and (D) are representative of threshold responses. The curvilinear smooth-fit line illustrates the points along the linear fit where change may be occurring, further supporting the sliding regression as a useful technique (see Ourso, 2001).

of our measures, were probably too short for an accurate accounting of sinuosity. However, sinuosity has been observed to be lower in urban streams compared to reference streams (Pizzuto et al., 2000). Increasing substrate embeddedness and bank erosion have been observed to increase in developing areas (Arnold et al., 1982; Furniss et al., 1991), but reach > 20% embedded and percent bank erosion are both subjective measures. Both variables had the lowest coefficient of determination values ($r^2 = 0.3170$ and 0.2017, respectively) of all significantly correlated variables. Although both showed threshold responses to PIA, the spread of points renders both highly suspect. A more quantitative measure for each, for example, digitized photos of substrate and streambanks, probably would provide more useful data. We feel that this is probably the case with many, if not most, subjective measures used in habitat monitoring and that such measures deserve further investigation.

In general, the macroinvertebrate community responded to PIA such that greater levels of PIA yielded taxonomically less diverse communities, composed of more disturbance-tolerant organisms. This is consistent with other studies of urban impacts on streams (Whiting & Clifford, 1983; Shutes, 1984; Garie & McIntosh, 1986; Kearns & Karr, 1994), especially a study by Jones & Clark (1987) that found the chironomid genera *Cricotopus* and *Orthocladius* associated with subbasins where PIA was high. Also characteristic of higher PIA sites were Tubificidae and Naididae worms, both highly tolerant to perturbation. Elevated concentrations of constituents associated with deicing salts may be related to the reduced diversity and greater abundance of tolerant organisms. Crowther & Hynes (1977) reported the possibility of degraded insect communities from road-salt-induced drift. Persistent exposure to even moderate levels of chemicals may act in a similar fashion by allowing the more tolerant organisms to dominate.

Conversely, subbasins with lower PIA were characterized by more diverse macroinvertebrate communities. Greater total taxa richness and EPT taxa richness at the family level (both characteristic of less perturbed environments, Table 3) were noted. The only significant metric related to functional feeding, percent shredder, was also negatively correlated with PIA. Shredders are those macroinvertebrates responsible for consuming coarse particulate organic matter which may create finer particles, and are most often associated with well canopied, headwater streams (Vannote et al., 1980).

Correlation (Spearman) analysis of macroinvertebrate metrics further demonstrated the validity of the gradient of urbanization illustrated by the first DCCA axis with respect to PIA. Increasing FBI and percent oligochaetes metrics were associated with increasing perturbation (Table 6). Both metrics were positively correlated with PIA as well as with the first DCCA axis (Tables 2 and 6), thereby suggesting that the site scores for urbanized areas were, in general, correctly predicted. Furthermore, metrics shown to decrease with increasing perturbation (EPT abundance; percentages of Ephemeroptera, scrapers, shredders, and EPT; and the ratio of EPT to Chironomidae) were negatively correlated with PIA and DCCA axis one (Tables 2 and 6). Therefore, subbasins with lower DCCA axis one scores tended to have lower PIA and support a greater diversity of organisms, including those considered intolerant to perturbation.

Campbell Creek was the possible exception with respect to site scores. C1 and C2 have higher DCCA axis one scores than would have been predicted by PIA alone (0.843 and 1.315, respectively). Given that PIA is higher in subbasins LR3 and R3, it could be assumed that C1 and C2 would be positioned to the left of LR3 and R3. Their shift to the right on the first DCCA axis may be attributed to natural differences associated with basin size (3rd order for C1, 4th order for C2) and related to the river continuum concept (Vannote et al., 1980). Slight changes in the macroinvertebrate community related to predictable downstream changes in feeding habits also were likely responsible for the shift to the right on the first DCCA axis.

The most urbanized sites, CH2, C3, and CH3, had PIA of at least 10% and macroinvertebrate communities characterized by more tolerant organisms than were present at sites with PIA less than 4%. Those subbasins are among the older residential areas in Anchorage and have population densities that would be categorized as urban using U.S. Census Bureau criterion of 386 persons/km^2. Rabbit and Little Rabbit Creek Basins have become developed as residential areas within the past 5–10 years and, at sites R2 and R3, population densities are approaching the urban category. Several of the threshold responses appeared to occur near sites R2 and R3, in other words, at PIA less than 10. Population densities at sites CH2 and C3 are similar, yet PIA at site C3 was twice that at CH2. Many of the measured responses at CH2 and C3 were similar, whereas CH2 appeared to be more similar to site CH3 with respect to chemical responses (Table 3).

The similarity of CH2 and CH3 in terms of chemical responses may be a function of streambed sediment chemistry integrating conditions at a larger scale than do some of the other measures.

Woody vegetation is well established along the banks at most sites, and along much of the lower parts of the Chester and Campbell Creek Basins, bike paths and parklands are adjacent to the creeks. This may explain why habitat variables related to riparian condition were not significantly correlated with PIA, as riparian buffer strips can successfully sustain many important habitat components (Schueler, 1995; Shaw & Bible, 1996). Urban development does exist in the flood plain at sites R2, R3, C2, C3, CH2, and CH3, but it is not reflected in the channel habitat variables measured. The extent of urban development in flood plains or within specified buffer distances from the channel may help explain the biological effects detected in this study.

Although the thresholds reported here appear low compared with values reported elsewhere (Schueler, 1994), the differences in this study may be related to the more advanced technology used to quantify PIA and the sliding regression technique used to determine threshold responses. Given that Landsat data used in many of the previous studies are at a 30-m resolution level, there is room for substantial misinterpretation related to a lack of precision. Had the technology used in this study been available for earlier investigations, a general reduction in detected response to PIA may have been possible. The low thresholds we observed also could relate to the local climate, as there are more extreme natural stressors on ecosystems in Alaska compared to those in more southerly latitudes. Future investigations using techniques discussed herein will aid in determining whether threshold responses to urbanization in Anchorage subbasins are actually low as a result of climatic differences or whether the greater resolution spatial data used in this study afforded better discernment of differences in PIA at lower levels.

Acknowledgements

We thank Matthew Whitman, Ted Moran, Dennis Estis, Dan Long, Stephanie Edmundson, and Janet Curran for their field assistance and data processing. Ted Moran was also responsible for spatial data and analyses. We also thank Terry Short and Humbert Zappia for their review of this document and the valuable insight they offered.

References

Arnold, C. L., P. J. Boison & P. C. Patton, 1982. Sawmill Brook: an example of rapid geomorphic change related to urbanization. J. Geol. 90: 155–166.

Arnold, C. L. & C. J. Gibbons, 1996. Impervious surface coverage – The emergence of a key environmental indicator. J. am. Plan. Assoc. 62: 243–258.

Baines, S. B., N. S. Fisher & R. Stewart, 2002. Assimilation and retention of selenium and other trace elements from crustacean food by juvenile striped bass (*Morone saxatilis*). Limnol. Oceanogr. 47: 646–655.

Barbour, M. T., G. L. Nelson, B. D. Snyder & J. B. Stribling, 1999. Rapid bioassessment protocols for use in streams and wadeable rivers – Periphyton, benthic macroinvertebrates, and fish (2nd edn). U.S. Environmental Protection Agency EPA 841-B-99-002.

Besser, J. M., W. G. Brumbaugh, T. W. May, S. E. Church & B. A. Kimball, 2001. Bioavailability of metals in stream food webs and hazards to brook trout (*Salvelinus fontinalis*) in the Upper Animas River Watershed, Colorado. Arch. Environ. Contam. Toxicol. 40: 48–59.

Booth, D. B., 1991. Urbanization and the natural drainage system—Impacts, solutions, and prognoses. Northwest Environ. J. 7: 93–118.

Booth, D. B. & C. R. Jackson, 1997. Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation. J. am. Wat. Resour. Assoc. 33: 1077–1090.

Brabets, T. P., G. L. Nelson, J. M. Dorava & A. M. Milner, 1999. Water-quality assessment of the Cook Inlet Basin, Alaska – Environmental Setting. U.S. Geological Survey Water-Resources Investigations Report 99–4025: 65 pp.

Canadian Council of Ministers for the Environment, 1999. Canadian sediment quality guidelines for the protection of aquatic life – Summary tables, in Canadian environmental quality guidelines, 1999: Winnipeg, Canadian Council of Ministers of the Environment.

Crowther, R. A. & H. B. N. Hynes, 1977. The effect of road deicing salt on the drift of stream benthos. Environ. Poll. 14: 113–126.

Cuffney, T. F., M. E. Gurtz & M. R. Meador, 1993. Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 93–406: 66 pp.

Deering, D. W., J. W. Rouse, R. H. Haas & J. A Schell, 1975. Measuring forage production of grazing units from Landsat MSS data. Proceedings, 10th International Symposium on Remote Sensing of Environment 2: 1169–1178.

Dinicola, R. S., 1989. Characterization and simulation of rainfall-runoff relations for headwater basins in western King and Snohomish Counties, Washington State. U.S. Geological Survey Water-Resources Investigations Report 89–4052: 52 pp.

Fitzpatrick, F. A., I. R. Waite, P. J. D'Arconte, M. R. Meador, M. A. Maupin & M. E. Gurtz, 1998. Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program.U.S. Geological Survey Water-Resources Investigations Report 98–4052: 67 pp.

Frenzel, S. A., 2000. Selected organic compounds and trace elements in streambed sediments and fish tissues, Cook Inlet Basin, Alaska. U.S. Geological Survey Water-Resources Investigations Report 00-4004: 39 pp.

Furniss, M. J., T. D. Roelofs & C. S. Lee, 1991. Road construction and maintenance. In Meehan, W. R. (ed.), Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society Special Publication 19, Bethesda (MD): 297–323.

Garie, H. L. & A. McIntosh, 1986. Distribution of benthic macroinvertebrates in a stream exposed to urban runoff. Wat. Res. Bull. 22: 447–451.

Gauch, H. G., Jr., 1982. Multivariate Analysis in Community Ecology. Cambridge University Press, New York: 298 pp.

Gilliom, R. J., D. K. Mueller & L. H. Nowell, 1998. Methods for comparing water-quality conditions among National Water-Quality Assessment study units, 1992–95. U.S. Geological Survey Open-File Report 97–589: 54 p.

Glass, R. L., 1999. Water-quality assessment of the Cook Inlet basin, Alaska – Summary of data through 1997. U.S. Geological Survey Water-Resources Investigations Report 99–4116: 110 p.

Hilsenhoff, W. L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. J. n. am. Benthol. Soc. 7: 65–68.

Jones, R. C. & C. C. Clark, 1987. Impact of watershed urbanization on stream insect communities. Wat. Res. Bull. 23: 1047–1055.

Kearns, B. L. & J. R. Karr, 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecol. Appl. 4: 768–785.

Klein, R. D., 1979. Urbanization and stream quality impairment. Wat. Res. Bull. 15: 948–963.

Koryak, M., L. J. Stafford, R. J. Reilly & P. M. Magnuson, 2001. Highway deicing salt runoff events and major ion concentrations along a small urban stream. J. Freshwat. Ecol. 16: 125–134.

Lemly, A. D., 1995. A protocol for aquatic hazard assessment of selenium. J. Ecotoxicol. Environ. Safety 32: 280–288.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar & E. B. Welch, 1997. Effects of urbanization on small streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques 2: 483–494.

McMahon, G. & T. F. Cuffney, 2000. Quantifying urban intensity in drainage basins for assessing stream ecological conditions. J. am. Wat. Resour. Ass. 36: 1247–1261.

Milner, A. M. & M. W. Oswood, 2000. Urbanization gradients in streams of Anchorage, Alaska: a comparison of multivariate and multimetric approaches to classification. Hydrobiologia 422/423: 209–223.

Moulton, S. R., II, J. L. Carter, S. A. Grotheer, T. F. Cuffney & T. M. Short, 2000. Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory – processing, taxonomy, and quality control of benthic macroinvertebrate samples. U.S. Geological Survey, Open-File Report 00–212: 49 pp.

MVSP, 1999. Multivariate Statistical Package, Version 3.1. Kovach Computing Services, Pentraeth, Wales, U.K.

Ourso, R. T., 2001. Effects of urbanization on benthic macroinvertebrate communities in streams, Anchorage, Alaska. U.S. Geological Survey Water-Resources Investigations Report 01-4278: 38 p.

Paul, M. J. & J. L. Meyer, 2001. Streams in the urban landscape. Ann. Rev. Ecol. Syst. (Palo Alto) 32: 333–365.

Pizzuto, J. E., W. C. Hession & M. McBride, 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania. Geology 28: 79–82.

Porcella, D. B. & D. L. Sorensen, 1980. Characteristics of non-point source urban runoff and its effects on stream ecosystems. EPA-600/3-80-032, Corvallis, Oregon: 99 pp.

Roth, N. E., J. D. Allan & D. L. Erickson, 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecol. 11: 141–156.

Schueler, T., 1994. The importance of imperviousness. Watershed Protection Techniques 1: 100–111.

Schueler, T., 1995. The architecture of urban stream buffers. Watershed Protection Techniques 1: 159–163.

Shaw, D. C. & K. Bible, 1996. An overview of forest canopy ecosystem functions with reference to urban and riparian systems. Northwest Sci. 70: 1–6.

Shelton, L. R., 1994. Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 94–455: 42 pp.

Shelton, L. R. & P. D. Capel, 1994. Guidelines for collecting and processing samples of stream bed sediment for analysis of trace elements and organic contaminants for the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 94–458: 20 pp.

Shutes, R. B. E., 1984. Influence of surface runoff on the macroinvertebrate fauna of an urban stream. Sci. Tot. Environ. 33: 271–282.

Sloane-Richey, J., M. A. Perkins & K. W. Malueg, 1981. The effects of urbanization and stormwater runoff on the food quality of two salmonid streams. Verh. int. Ver. Theor. Angew. Limnol. 21: 812–818.

StatSoft, Inc., 2001. STATISTICA, data analysis software system, version 6. http://www.statsoft.com.

Sutherland, R. A., 2000. Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. Environ. Geol. 39: 611–627.

Sutherland, R. A. & C. A. Tolosa, 2001. Variation in total and extractable elements with distance from roads in an urban watershed, Honolulu, Hawaii. Wat. Air Soil Poll. 127: 315–338.

Turer, D., J. B. Maynard & J. J. Sansalone, 2001. Heavy metal contamination in soils of urban highways: comparison between runoff and soil concentrations at Cincinnati, Ohio. Wat. Air Soil Poll. 132: 293–314.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedel & C. E. Cushing, 1980. The river continuum concept. Can. J. Fish. aquat. Sci. 37: 130–137.

Wang, L., J. Lyons, P. Kanehl, R. Bannerman & E. Emmons, 2000. Watershed urbanization and changes in fish communities in southeastern Wisconsin streams. J. am. Wat. Resour. Assoc. 36: 1173–1189.

Waters, T. F., 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society Monographs 7: 251 pp.

Wear, D. N., M. G. Turner & R. J. Naiman, 1998. Land cover along an urban-rural gradient: implications for water quality. Ecol. Appl. 8: 619–630.

Whiting, E. R. & H. F. Clifford, 1983. Invertebrates and urban runoff in a small northern stream, Edmonton, Alberta, Canada. Hydrobiologia 102: 73–80.

Winter, J. G. & H. C. Duthie, 1998. Effects of urbanization on water quality, periphyton and invertebrate communities in a southern Ontario stream. Can. Wat. Res. J. 23: 245–257.

Zar, J. H., 1996. Biostatistical Analysis. Prentice Hall, New Jersey: 662 pp.

Appendix 1. Spearman correlations between all variables examined and subbasin impervious area. [Bold values indicate significant correlations at $P < 0.05$]

PIA vs Variable Spearman	*R*	*P*-level
Channel Condition		
Sinuousity	–0.844	**0.0006**
Reach Length	0.262	0.4100
Average Bankfull Width/Depth	0.000	1.0000
Bank Stability Index	0.274	0.3894
Percent Bank Erosion Abundance	–0.671	**0.0168**
Percent Riparian Closure	0.231	0.4705
Percent Shade	0.077	0.8122
Percent Riffle Length	–0.363	0.2461
Percent Run Length	0.292	0.3573
Percent Pool Length	–0.058	0.8573
Instream Habitat		
Percent Habitat Abundance	0.054	0.8682
Percent Woody Debris Abundance	0.527	0.0782
Percent Vegetation Abundance	–0.180	0.5751
Percent Boulder Habitat Abundance	0.367	0.2404
Percent Manmade Habitat Abundance	0.303	0.3391
Percent Undercut Bank Abundance	–0.467	0.1262
Percent Dominant Silt	0.179	0.5769
Percent Dominant Sand	0.225	0.4825
Percent Dominant Fine/Medium Gravel	0.075	0.8158
Percent Dominant Coarse Gravel	0.181	0.5730
Percent Dominant Very Coarse Gravel	0.211	0.5106
Percent Dominant Small Cobble	–0.310	0.3270
Percent Dominant Large Cobble	–0.070	0.8284
Percent Dominant Small Boulder	0.147	0.6483
Percent Reach 0 Percent Embedded	–0.487	0.1085
Percent Reach 1–20 Percent Embedded	0.451	0.1412
Percent Reach >20 Percent Embedded	0.587	**0.0448**
Percent Silt Abundance	0.401	0.1959
Macroinvertebrate Metrics		
Shannon Wiener Diversity Index	–0.294	0.3541
Total Abundance	0.056	0.8629
EPT Abundance	–0.734	**0.0065**
Hilsenhoff Family-level Biotic Index	0.748	**0.0051**
Percent Chironomidae	0.035	0.9141
Percent Ephemeroptera	–0.557	0.0600
Percent Plecoptera	–0.545	0.0666
Percent Trichoptera	–0.480	0.1144
Percent Oligochaeta	0.566	0.0548
Percent Filterer	–0.028	0.9312
Percent Collector	0.214	0.5049
Percent Predator	–0.049	0.8799
Percent Scraper	–0.564	0.0559

Appendix 1. contd.

Percent Shredder	–0.608	**0.0358**
Total Taxa Richness	–0.370	0.2360
(lowest practical taxonomic identification)		
Total Family Richness	–0.651	**0.0218**
Percent Dominant Taxa - 2	0.361	0.2484
Percent EPT	–0.587	**0.0446**
EPT Taxa Richness	–0.740	**0.0059**
Percent EPT to Chironomidae	–0.539	0.0703
Percent Baetidae to Ephemeroptera	0.371	0.2347
Water Chemistry		
Discharge	0.308	0.3297
Dissolved Oxygen	–0.466	0.1269
pH	0.171	0.5941
Specific Conductance	0.503	0.0952
Calcium	0.545	0.0666
Magnesium	0.510	0.0899
Potassium	0.340	0.2803
Sodium	0.610	**0.0351**
Chloride	0.788	**0.0023**
Silica	0.182	0.5717
Sulfate	0.566	0.0548
Nitrate	–0.161	0.6175
Total Phosphorus	0.511	0.0892
Dissolved Organic Carbon	0.141	0.6624
Residue	0.524	0.0800
Iron	0.732	**0.0068**
Manganese	0.800	**0.0018**
Stream Density	–0.042	0.8970
Sediment Chemistry		
Phosphorus (sediment)	–0.372	0.2344
Sodium	0.373	0.2329
Magnesium	0.512	0.0885
Potassium	–0.243	0.4467
Iron	0.377	0.2264
Calcium	–0.245	0.4436
Aluminum	–0.111	0.7319
Organic Carbon	–0.503	0.0952
Inorganic Carbon	–0.190	0.5543
Total Carbon	–0.503	0.0952
Selenium	–0.913	**<0.0001**
Arsenic	0.133	0.6795
Cadmium	0.659	**0.0198**
Silver	0.118	0.7143
Zinc	0.866	**0.0003**
Lead	0.651	**0.0219**
Nickel	0.650	**0.0220**
Molybdenum	–0.315	0.3184
Manganese	0.267	0.4013

Is Impervious Cover Still Important? Review of Recent Research

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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.

DOI: 10.1061/(ASCE)1084-0699(2009)14:4(309)

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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Note. Discussion open until September 1, 2009. Separate discussions must be submitted for individual papers. The manuscript for this paper was submitted for review and possible publication on January 30, 2008; approved on October 4, 2008. This paper is part of the ***Journal of Hydrologic Engineering***, Vol. 14, No. 4, April 1, 2009. ©ASCE, ISSN 1084-0699/2009/4-309–315/$25.00.

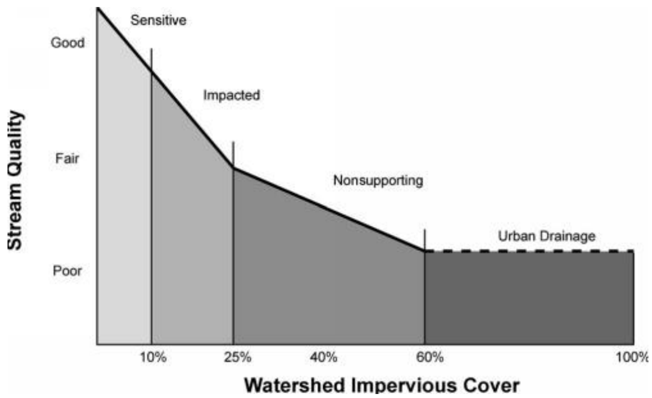


Fig. 1. Impervious cover model [adapted from CWP (1998)]

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

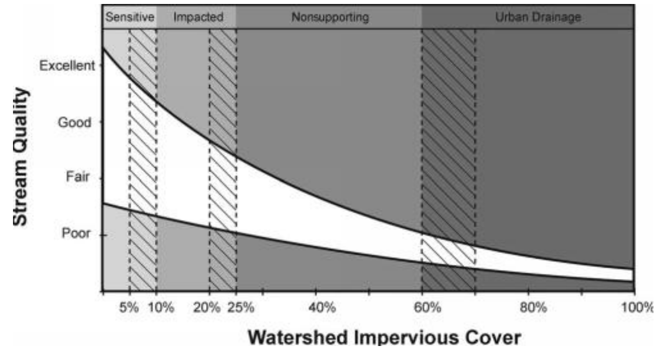


Fig. 2. Reformulated impervious cover model

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.

Article 1

Feature article from Watershed Protection Techniques. 1(3): 100-111

The Importance of Imperviousness

The emerging field of urban watershed protection often lacks a unifying theme to guide the efforts of its many participants—planners, engineers, landscape architects, scientists, and local officials. The lack of a common theme has often made it difficult to achieve a consistent result at either the individual development site or cumulatively, at the watershed scale.

In this article a unifying theme is proposed based on a physically defined unit: imperviousness. Imperviousness here is defined as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape. This variable can be easily measured at all scales of development, as the percentage of area that is not "green."

Imperviousness is a very useful indicator with which to measure the impacts of land development on aquatic systems. Reviewed here is the scientific evidence that relates imperviousness to specific changes in the hydrology, habitat structure, water quality and biodiversity of aquatic systems. This research, conducted in many geographic areas, concentrating on many different variables, and employing widely different methods, has yielded a surprisingly similar conclusion: stream degradation occurs at relatively low levels of imperviousness (~10%). Most importantly, imperviousness is one of the few variables that can be explicitly quantified, managed and controlled at each stage of land development. The remainder of this article details the relationship between imperviousness and stream quality.

The Components of Imperviousness

Imperviousness represents the imprint of land development on the landscape. It is composed of two primary components: the *rooftops* under which we live, work and shop, and the *transport* system (roads, driveways, and parking lots) that we use to get from one roof to another. As it happens, the transport component now often exceeds the rooftop component in terms of total impervious area created. For example, transport-related imperviousness comprised 63 to 70% of total impervious cover at the site in 11 residential, multifamily and commercial areas where it had actually been measured (City of Olympia, 1994b). This phenomenon is observed most often in suburban areas and reflects the recent ascendancy of the automobile in both our culture and landscape. The sharp increases in per capita vehicle ownership, trips taken, and miles travelled have forced local planners to increase the relative size of the transport component of imperviousness over the last two decades.

Traditional zoning has strongly emphasized and regulated the first component (rooftops) and largely neglected the transport component. While the rooftop component is largely fixed in zoning, the transport component is not. As an example, nearly all zoning codes set the maximum density for an area, based on dwelling units or rooftops. Thus, in a given area, no more than one single family home can be located on each acre of land, and so forth.

Thus, a wide range in impervious cover is often seen for the same zoning category. For example, impervious area associated with medium density single family homes can range from 20% to nearly 50%, depending on the layout of streets and parking. This suggests that significant opportunities exist to reduce the share of imperviousness from the transport component.

Imperviousness and Runoff

The relationship between imperviousness and runoff may be widely understood, but it is not always fully appreciated. Figure 1 illustrates the increase in the site runoff coefficient as a result of site impervious cover, developed from over 40 runoff monitoring sites across the nation. The runoff coefficient ranges from zero to one and expresses the fraction of rainfall volume that is actually converted into storm runoff volume. As can be seen, the runoff coefficient closely tracks percent impervious cover, except at low levels where soils and slope factors become more important. In practical terms, this means that the total runoff volume for a one-acre parking lot (Rv = 0.95) is about 16 times that produced by an undeveloped meadow (Rv = 0.06).

To put this in more understandable terms, consider the runoff from a one-inch rainstorm (see Table 1). The total runoff from a one-acre meadow would fill a standard size office to a depth of about two feet (218 cubic feet). By way of comparison, if that same acre was completely paved, a one-inch rainstorm would completely fill your office, as well as the *two* next to it. The peak discharge, velocity and time of concentration of stormwater runoff also exhibit a striking increase after a meadow is replaced by a parking lot (Table 1).

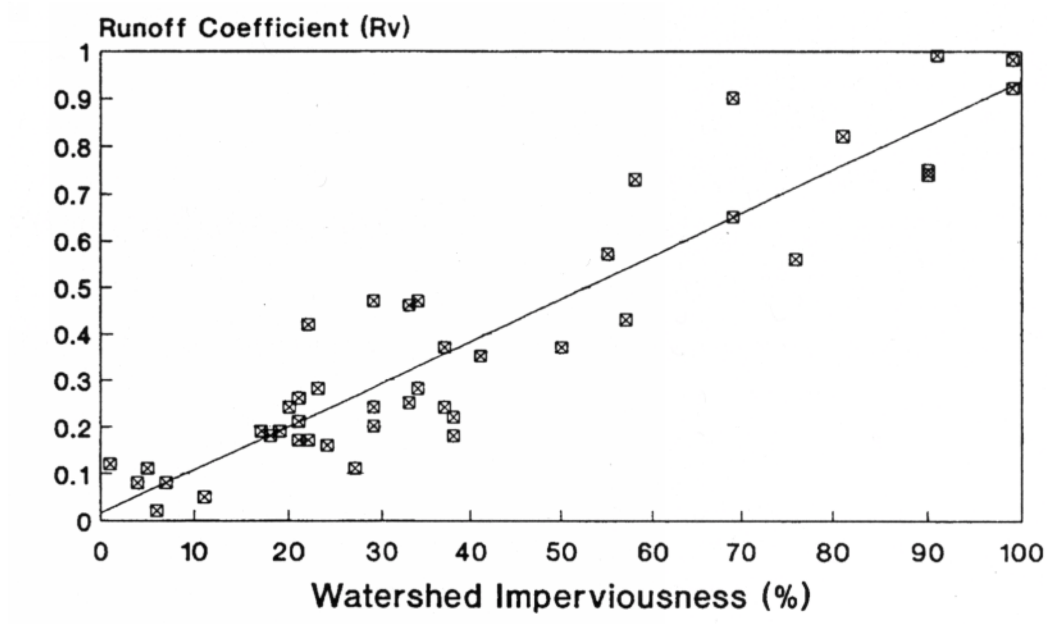


Figure 1: Watershed Imperviousness and the Storm Runoff Coefficient

Because infiltration is reduced in impervious areas, one would expect groundwater recharge to be proportionately reduced. This, in turn, should translate into lower dry weather stream flows. Actual data, however, that demonstrate this effect is rare. Indeed, Evett *et al.* (1994) could not find any statistical difference in low stream flow between urban and rural watersheds after analyzing 16 North Carolina watersheds. Simmons and Reynolds (1982) did note that dry weather flows dropped 20 to 85% after development in several urban watersheds in Long Island, New York.

It should be noted that transport-related imperviousness often exerts a greater hydrological impact than the rooftop-related imperviousness. In residential areas, runoff from rooftops can be spread out over pervious areas, such as backyards, and rooftops are not always directly connected to the storm drain system. This may allow for additional infiltration of runoff. Roads and parking lots, on the other hand, are usually directly connected to the storm drain system.

Table 1: Comparison of One Acre of Parking Lot Versus One Acre of Meadow in Good Condition

Runoff or Water Quality Parameter	Parking Lot	Meadow
Curve number (CN)	98	58
Runoff coefficient	0.95	0.06
Time of concentration (minutes)	4.8	14.4
Peak discharge rate (cfs), 2 yr., 24 hr. storm	4.3	0.4
Peak discharge rate (cfs), 100 yr. storm	12.6	3.1
Runoff volume from one-inch storm (cubic feet)	3450	218
Runoff velocity @ 2 yr. storm (feet/second)	8	1.8
Annual phosphorus load (lbs/ac./yr.).	2	0.50
Annual nitrogen load (lbs/ac./yr.).	15.4	2.0
Annual zinc load (lbs/ac./yr.)	0.30	ND

Key Assumptions:
Parking lot is 100% impervious with 3% slope, 200 feet flow length, Type 2 Storm, 2 yr. 24 hr. storm = 3.1 inches, 100 yr. storm = 8.9 inches, hydraulic radius = 0.3, concrete channel, and suburban Washington 'C' values.
Meadow is 1% impervious with 3% slope, 200 foot flow length, good vegetative condition, B soils, and earthen channel.

Imperviousness and the Shape of Streams

Confronted by more severe and more frequent floods, stream channels must respond. They typically do so by increasing their cross-sectional area to accommodate the higher flows. This is done either through widening of the stream banks, downcutting of the stream bed, or frequently, both. This phase of channel instability, in turn, triggers a cycle of streambank erosion and habitat degradation.

The critical question is at what level of development does this cycle begin? Recent research models developed in the Pacific Northwest suggest that a threshold for urban stream stability exists at about 10% imperviousness (Booth, 1991; Booth and Reinelt, 1993) (Figure 2). Watershed development beyond this threshold consistently resulted in unstable and eroding channels. The rate and severity of channel instability appears to be a function of sub-bankfull floods, whose frequency can increase by a factor of 10 even at relatively low levels of imperviousness (Hollis, 1975; Macrae and Marsalek, 1992; Schueler, 1987).

A major expression of channel instability is the loss of instream habitat structures, such as the loss of pool and riffle sequences and overhead cover, a reduction in the wetted perimeter of the stream and the like. A number of methods have been developed to measure the structure and quality of instream habitat in recent years (Galli, 1993; Gibson *et al.*, 1993; Plafkin *et al*., 1989). Where these tools have been applied to urban streams, they have consistently demonstrated that a sharp threshold in habitat quality exists at approximately 10 to 15% imperviousness (Booth and Reinelt, 1993; Galli, 1994; Shaver *et al*., 1995). Beyond this threshold, urban stream habitat quality is consistently classified as poor.

Imperviousness and Water Quality

Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other sources. During storms, accumulated pollutants are quickly washed off and rapidly delivered to aquatic systems.

Monitoring and modeling studies have consistently indicated that urban pollutant loads are directly related to watershed imperviousness. Indeed, imperviousness is the key predictive variable in most simulation and empirical models used to estimate pollutant loads. For example, the Simple Method assumes that pollutant loads are a direct function of watershed imperviousness (Schueler, 1987), as imperviousness is the key independent variable in the equation.

Threshold Limits for Maintaining Background Pollutant Loads

Suppose that watershed runoff drains into a lake that is phosphorus-limited. Also assume that the present background load of phosphorus from a rural land use amounts to 0.5 lbs/ac/yr. The Simple Method predicts that the post-development phosphorus load will exceed background loads once watershed imperviousness exceeds 20 to 25% (Figure 3), thereby increasing the risk of nutrient over-enrichment in the lake.

Urban phosphorus loads can be reduced when urban stormwater treatment practices are installed, such as stormwater ponds, wetlands, filters or infiltration practices. Performance monitoring data indicates that stormwater practices can reduce phosphorus loads by as much as 40 to 60%, depending on the practice selected. The impact of this pollutant reduction on the post-development phosphorus loading rate from the site is shown in Figure 3. The net effect is to raise the phosphorus threshold to about 35 to 60% imperviousness, depending on the performance of the stormwater practice installed. Therefore, even when effective practices are widely applied, a threshold of imperviousness is eventually crossed, beyond which predevelopment water quality cannot be maintained.

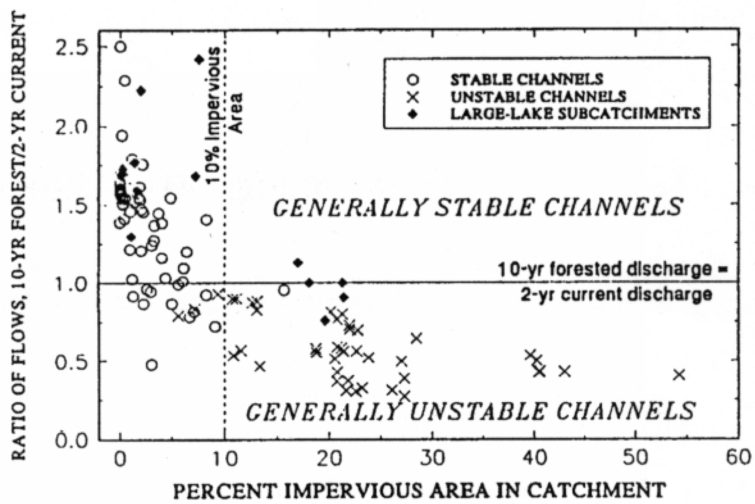


Figure 2: Channel Stability as a Function of Imperviousness (Booth and Reinelt, 1993)

Imperviousness and Stream Warming

Impervious surfaces both absorb and reflect heat. During the summer months, impervious areas can have local air and ground temperatures that are 10 to 12 degrees warmer than the fields and forests that they replace. In addition, the trees that could have provided shade to offset the effects of solar radiation are absent.

Water temperature in headwater streams is strongly influenced by local air temperatures. Galli (1991) reported that stream temperatures throughout the summer are increased in urban watersheds, and the degree of warming appears to be directly related to the impervious cover of the contributing watershed. He monitored five headwater streams in the Maryland Piedmont over a six-month period, each of which had different levels of impervious cover (Figure 4). Each of the urban streams had mean temperatures that were consistently warmer than a forested reference stream, and the size of the increase (referred to as the delta-T) was a direct function of watershed imperviousness. Other factors, such as lack of riparian cover and ponds, were also demonstrated to amplify stream warming, but the primary contributing factor appeared to be watershed impervious cover (Galli, 1991).

Imperviousness and Stream Biodiversity

The health of the aquatic ecosystem is a strong environmental indicator of watershed quality. A number of research studies have recently examined the links between imperviousness and the biological diversity in streams. Some of the key findings are summarized in Table 2.

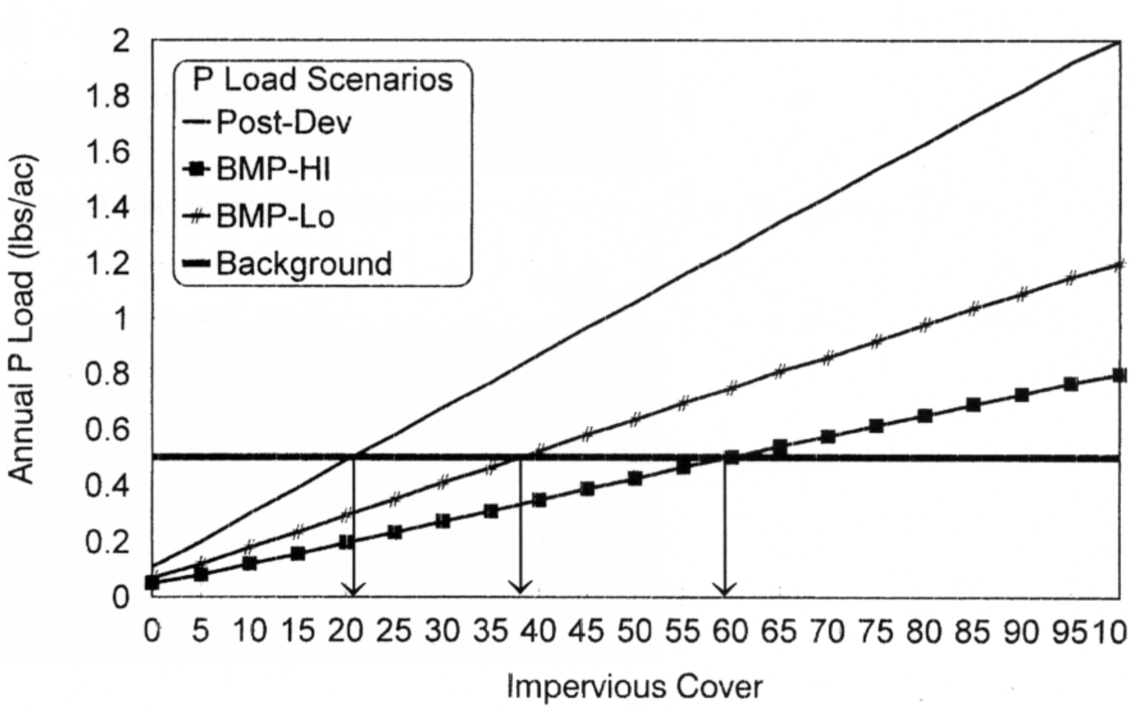


Figure 3: The Effect of Impervious Cover on Urban Phosphorus Load Under Several Scenarios, as Computed by the Simple Method

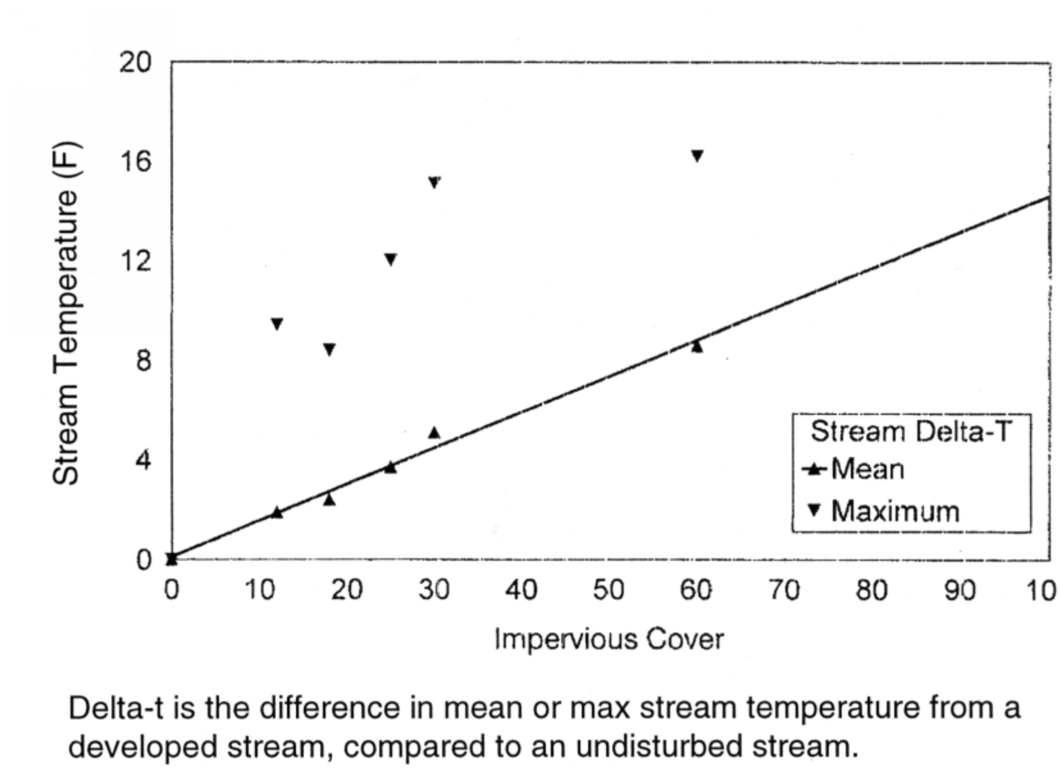
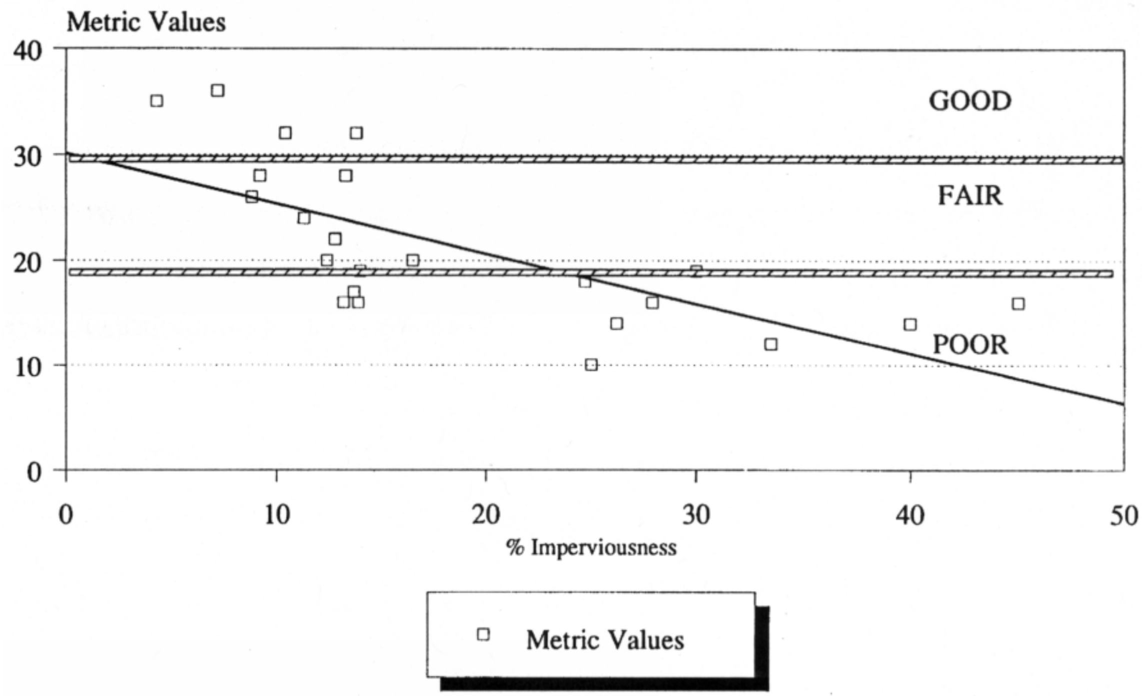


Figure 4: The Effect of Impervious Cover on Stream Temperature (Galli, 1991)



Metric Values are based upon the sum of scores assigned for the following categories: EPTC balance, EPT Index, Average Generic Diversity, Chironomid Abundance, Taxonomic Richness (Family and Generic)

Figure 5: Impacts of Imperviousness on Macroinvertebrate Communities in the Headwater Streams of the Anacostia River (Schueler and Galli, 1992)

Aquatic Insects

The diversity, richness and composition of the aquatic insect community has frequently been used to evaluate the quality of urban streams. Not only are aquatic insects a useful environmental indicator, but they also form the base of the stream food chain in most regions of the country.

Klein (1979) was one of the first to note that macroinvertebrate diversity drops sharply in urban streams in Maryland. Diversity consistently became poor when watershed imperviousness exceeded 10 to 15%. The same basic threshold has been reported by all other research studies that have looked at macroinvertebrate diversity in urban streams (Table 2).

In each study, sensitive macroinvertebrates were replaced by ones that were more tolerant of pollution and hydrologic stress. Species such as stoneflies, mayflies, and caddisflies largely disappeared and were replaced by chironomids, tubificid worms, amphipods, and snails. Species that employ specialized feeding strategies—shredding leaf litter, grazing rock surfaces, filtering organic matter that flows by, or preying on other insects—were lost.

A typical example of the relationship between imperviousness and macroinvertebrate diversity is shown in Figure 5. The graph summarizes diversity trends for 23 sampling stations in headwater streams of the Anacostia watershed (Schueler and Galli, 1992). While good to fair diversity was noted in all headwater streams with less than 10% impervious cover, nearly all stations with 12% or more impervious cover recorded poor diversity. The same sharp drop in macroinvertebrate diversity at around 12 to 15% impervious cover was also observed in streams in the coastal plain and piedmont of Delaware (Shaver *et al.,* 1995).

Other studies have utilized other indicators to measure the impacts of urbanization on stream insect communities. For example, Jones and Clark (1987) monitored 22 stations in Northern Virginia and concluded that aquatic insect diversity composition changed markedly after watershed population density exceeded four or more individuals per acre. This population density roughly translates to half-acre or one acre lot residential use, or perhaps 10 to 15% imperviousness.

Steedman (1988) evaluated 208 Ontario stream sites, and concluded that aquatic insect diversity shifted from fair to poor at about 35% urban land use. Since "urban land" includes both pervious and impervious cover, the actual threshold in the Ontario study may well be closer to seven to 10% imperviousness (Booth and Reinelt, 1993). Steedman also reported that urban streams with intact riparian forests had higher diversity than those that did not, for the same level of urbanization.

While the exact point at which stream insect diversity shifts from fair to poor is not known with absolute precision, it is clear that few, if any, urban streams can

Table 2: Review of Key Findings of Urban Stream Studies Examining the Relationship of Urbanization to Stream Quality

Ref.	Year	Location	Biological Parameter	Key Finding
Booth	1991	Seattle	Fish habitat/ channel stability	Channel stability and fish habitat quality declined rapidly after 10% imperv.
Galli	1994	Maryland	Brown trout	Abundance and recruitment of brown trout declines sharply at 10-15% imperv.
Benke *et al.*	1981	Atlanta	Aquatic insects	Negative relationship between number of insect species and urbanization in 21 streams
Jones and Clark	1987	Northern Virginia	Aquatic insects	Urban streams had sharply lower diversity of aquatic insects when human population density exceeded 4 persons/acre. (estimated 15-25% imperv. cover)
Limburg and Schimdt	1990	New York	Fish spawning	Resident and anadromous fish eggs and larvae declined sharply in 16 tributary streams greater than 10% imperv.
Shaver *et al.*	1994	Delaware	Aquatic insects	Insect diversity at 19 stream sites dropped sharply at 8 to 15% imperv.
Shaver *et al.*	1994	Delaware	Habitat quality	Strong relationship between insect diversity and habitat quality; majority of 53 urban streams had poor habitat
Schueler and Galli	1992	Maryland	Fish	Fish diversity declined sharply with increasing imperv., loss in diversity began at 10-12% imperv.
Schueler and Galli	1992	Maryland	Aquatic insects	Insect diversity metrics in 24 subwatersheds shifted from good to poor over 15% imperv.
Black and Veatch	1994	Maryland	Fish/insects	Fish, insect and habitat scores were all ranked as poor in 5 subwatersheds that were greater than 30% imperv.
Klein	1979	Maryland	Aquatic insects/fish	Macroinvertebrate and fish diversity declines rapidly after 10% imperv.
Luchetti and Fuersteburg	1993	Seattle	Fish	Marked shift from less tolerant coho salmon to more tolerant cutthroat trout populations noted at 10-15% imperv. at 9 sites
Steedman	1988	Ontario	Aquatic insects	Strong negative relationship between biotic integrity and increasing urban land use/ riparian condition at 209 stream sites. Degradation begins at about 10% imperv.
Pedersen and Perkins	1986	Seattle	Aquatic insects	Macroinvertebrate community shifted to chironomid, oligochaetes and amphipod species tolerant of unstable conditions.
Steward	1983	Seattle	Salmon	Marked reduction in coho salmon populations noted at 10-15% imperv. at 9 sites
Taylor	1993	Seattle	Wetland plants/ amphibians	Mean annual water fluctuation was inversely correlated to plant and amphibian density in urban wetlands. Sharp declines noted over 10% imperv.
Garie and McIntosh	1986	New Jersey	Aquatic insects	Drop in insect taxa from 13 to 4 noted in urban streams
Yoder	1991	Ohio	Aquatic insects/ fish	100% of 40 urban sites sampled had fair to very poor index of biotic integrity scores

support diverse aquatic insect communities at moderate to high levels of impervious cover (25% or more). Four different studies (Benke *et al*., 1981; Black and Veatch, 1994; Booth, 1991; Garie and McIntosh, 1986) all failed to find aquatic insect communities with good or excellent diversity in these highly urban streams.

Fish Surveys

The abundance and diversity of the fish community can also serve as an excellent environmental indicator. Surprisingly, relatively few studies have examined the influence of imperviousness on fish communities in headwater streams. The results of one study are illustrated in Figure 6. Four similar subwatersheds in the Maryland Piedmont were sampled for the number of fish species present. As the level of watershed imperviousness increased, the number of fish species collected dropped. Two sensitive species (trout and sculpin) were lost as imperviousness increased from 10 to 12%, and four more were lost when impervious cover increased to 25%. Significantly, only two species remained in the fish community at 55% imperviousness. Sensitive species, defined as those with a strong dependence on the substrate for feeding and/or spawning, showed a more precipitous decline. Klein (1979) found a similar relationship between fish diversity and watershed impervious cover in several dozen headwater streams in the Maryland Piedmont.

Salmonid fish species (trout and salmon) and anadromous fish species appear to be most negatively impacted by impervious cover. Trout have stringent temperature and habitat requirements, and seldom are present in mid-Atlantic watersheds where imperviousness exceeds 15% (Galli, 1994). Declines in trout spawning success are evident above 10% imperviousness (Galli, 1994). In the Pacific Northwest, Luchetti and Feurstenburg (1993) seldom found sensitive coho salmon in watersheds beyond 10 or 15% imperviousness. Booth and Reinelt (1993) noted that most urban stream reaches had poor quality fish habitat when imperviousness exceeded eight to 12%.

Fish species that migrate from the ocean to spawn in freshwater creeks are also very susceptible to impacts of urbanization such as fish barriers, pollution, flow changes, and other factors. For example, Limburg and Schmidt (1990) discovered that the density of anadromous fish eggs and larvae declined sharply after a 10% imperviousness threshold was surpassed in 16 subwatersheds draining into the Hudson River.

The Influence of Imperviousness on Other Urban Water Resources

Several other studies point to the strong influence of imperviousness on other important aquatic systems such as shellfish beds and wetlands.

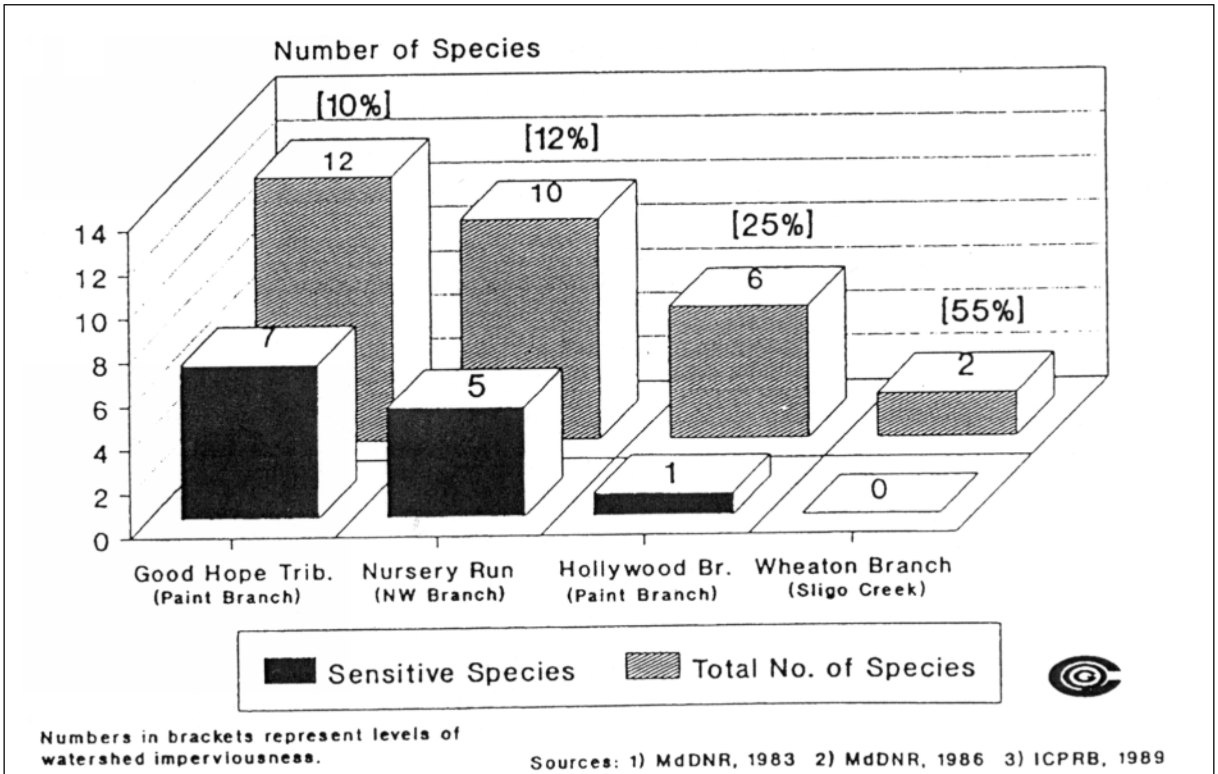


Figure 6: Fish Diversity as a Function of Watershed Imperviousness in Four Subwatersheds in the Maryland Piedmont (Schueler and Galli, 1992)

Even relatively low levels of urban development yield high levels of bacteria, derived from urban runoff or failing septic systems. These consistently high bacterial counts often result in the closure of shellfish beds in coastal waters, and it is not surprising that most closed shellfish beds are in close proximity to urban areas. Indeed, it may be difficult to prevent shellfish closure when more than one septic drain field is present per seven acres—a very low urban density (Duda and Cromartie, 1982). Although it is widely believed that urban runoff accounts for many shellfish bed closures (now that most point sources have been controlled), no systematic attempt has yet been made to relate watershed imperviousness to the extent of shellfish bed closures.

Taylor (1993) examined the effect of watershed development on 19 freshwater wetlands in King County, Washington, and concluded that the additional stormwater contributed to greater annual water level fluctuations (WLF). When the annual WLF exceeded about eight inches, the richness of both the wetland plant and amphibian community dropped sharply. This increase in WLF began to occur consistently when upstream watersheds exceeded 10 to 15% imperviousness.

Implications at the Watershed Level

The many independent lines of research reviewed here converge toward a common conclusion: that it is extremely difficult to maintain predevelopment stream quality when watershed development exceeds 10 to 15% impervious cover. What implications might this apparent threshold have for watershed planning?

Should Low Density or High Density Development be Encouraged?

At first glance, it would seem appropriate to limit watershed development to no more than 10% total impervious cover. While this approach may be wise for an individual "sensitive" watershed, it is probably not practical as a uniform standard. Only low density development would be feasible under a 10% zoning scenario, perhaps one-acre lot residential zoning, with a few widely scattered commercial clusters. At the regional scale, development would thus be spread over a much wider geographic area than it would otherwise have been. At the same time, additional impervious area (in the form of roads) would be needed to link the community together.

Paradoxically, the best way to minimize the creation of additional impervious area at the regional scale is to concentrate it in high density clusters or centers. The corresponding impervious cover in these clusters is expected to be very high (25% to 100%), making it virtually impossible to maintain predevelopment stream quality. A watershed manager must then confront the fact that to save one stream's quality it may be necessary to degrade another.

A second troubling implication of the impervious cover/stream quality relationship involves the large expanses of urban areas that have already been densely developed. Will it be possible to fully restore stream quality in watersheds with high impervious cover? Some early watershed restoration work does suggests that biological diversity in urban streams can be partially restored, but only after extensive stormwater retrofit and habitat structures are installed. For example, fish and macroinvertebrate diversity has been partially restored in one tributary of Sligo Creek, Maryland (Galli, 1994). In other urban watersheds, however, comprehensive watershed restoration may not be feasible, due to a lack of space, feasible sites, or funding.

A Proposed Scheme for Classifying Urban Stream Quality Potential

The thresholds provide a reasonable foundation for classifying the potential stream quality in a watershed based on the ultimate amount of impervious cover. One such scheme is outlined in Table 3. It divides urban streams into three management categories based on the general relationship between impervious cover and stream quality:

1. Sensitive streams (one to 10% impervious cover)
2. Impacted streams (11 to 25% impervious cover)
3. Non-supporting streams (26 to 100% impervious cover)

The resource objective and management strategies in each stream category differ to reflect the potential stream quality that can be achieved. The most protective category are "sensitive streams" in which strict zoning, site impervious restrictions, stream buffers and stormwater practices are applied to maintain predevelopment stream quality. "Impacted streams" are above the threshold and can be expected to experience some degradation after development (i.e., less stable channels and some loss of diversity). The key resource objective for these streams is to mitigate these impacts to the greatest extent possible, using effective stormwater management practices.

The last category, "non-supporting streams," recognizes that predevelopment channel stability and biodiversity cannot be fully maintained, even when stormwater practices or retrofits are fully applied. The primary resource objective shifts to protect downstream water quality by removing urban pollutants. Efforts to protect or restore biological diversity in degraded streams are not abandoned; in some priority subwatersheds, intensive stream restoration techniques

Table 3: A Possible Scheme for Classifying and Managing for Headwater Urban Streams Based on Ultimate Imperviousness

Urban Stream Classification	Sensitive (0-10% Imperv.)	Impacted (11-25% Imperv.)	Non-supporting (26-100% Imperv.)
Channel stability	Stable	Unstable	Highly Unstable
Water quality	Good	Fair	Fair-Poor
Stream biodiversity	Good-Excellent	Fair-Good	Poor
Resource objective	Protect biodiversity and channel stability	Maintain critical elements of stream quality	Minimize downstream pollutant loads
Water quality objectives	Sediment and temperature	Nutrient and metal loads	Control bacteria
Stormwater Practice Selection Factors	Secondary environmental impacts	Removal efficiency	Removal efficiency
Land Use Controls	Watershed-wide imp. cover limits (ICLs), site ICLs	Site imp. cover limits (ICLs)	Additional infill and redevelopment encouraged
Monitoring and enforcement	GIS monitoring of imp. cover, biomonitoring	Same as “Stressed”	Pollutant load modeling
Development rights	Transferred out	None	Transferred in
Riparian buffers	Widest buffer network	Average bufferwidth	Greenways

are employed to attempt to partially restore some aspects of stream quality. In other subwatersheds, however, new development (and impervious cover) is encouraged to protect other sensitive or impacted streams.

Watershed-Based Zoning

Watershed-based zoning is based on the premise that impervious cover is a superior measure for gauging the impacts of growth, compared to population density, dwelling units or other factors. The key steps in watershed-based zoning are as follows: *First*, a community undertakes a comprehensive physical, chemical and biological monitoring program to asses the current quality of its entire inventory of streams. The data are used to identify the most sensitive stream systems and to refine impervious/stream quality relationships. *Next*, existing impervious cover is measured and mapped at the subwatershed level. Projections of future impervious cover due to forecasted growth are also made at this time.

The *third* step involves designating the future stream quality for each subwatershed based on some adaptation of the urban stream classification scheme presented earlier. The existing land use master plan is then modified to ensure that future growth (and impervious cover) is consistent with the designated stream classification for each subwatershed.

The *final* step in the watershed-based zoning process involves the adoption of specific resource objectives for each stream and subwatershed. Specific policies and practices on impervious cover limits, stormwater practices, and buffers are then instituted to meet the stream resource objective, and these practices directly applied to future development projects.

Watershed-based zoning should provide managers with greater confidence that resource protection objectives can be met in future development. It also forces local governments to make hard choices about which streams will be fully protected and which will become at least partially degraded. Some environmentalists and regulators will be justifiably concerned about the streams whose quality is explicitly sacrificed under this scheme. However, the explicit stream quality decisions which are at the heart of watershed-based zoning are preferable to the uninformed and random “non-decisions” that are made every day under the present zoning system.

A Cautionary Note

While the research on impervious cover and stream quality is compelling, it is doubtful whether it can serve as the sole foundation for legally defensible zoning and regulatory actions at the current time. One key reason is that the research has not been standardized. Different investigators, for example, have used different methods to define and measure imperviousness. Second, researchers have employed a wide number of techniques to measure stream quality characteristics that are not always comparable with each other. Third, most of the studies have been confined to few ecoregions in the country. Little research has been conducted in the Northeast, Southeast, Midwest, and semi-arid Western regions. Lastly, none of the studies has yet examined the effect of widespread application of stormwater practices on impervious cover/stream quality relationships. Until studies determine how much stormwater practices can "cheat" the impervious cover/stream quality relationship, it can be argued that structural practices alone can compensate for imperviousness effects.

On the positive side, it may be possible for a community to define the impervious cover/stream quality relationship in a short time and at relatively low cost. A suggested protocol for conducting a watershed monitoring study is presented in Table 4. The protocol emphasizes comparative sampling of a large population of urban subwatersheds of different increments of imperviousness (perhaps 20 to 50).

A rapid sampling program collects consistent data on hydrologic, morphologic, water quality, habitat and biodiversity variables within each subwatershed. For comparison purposes, series of undeveloped and undisturbed reference streams are also monitored. The sampling data are then statistically and graphically analyzed to determine the presence of imperviousness/stream quality relationships.

The protocol can be readily adapted to examine how stormwater practices can shift the stream quality/imperviousness relationship. This is done by adjusting the sampling protocol to select two groups of study subwatersheds: those that are effectively served by stormwater practices and those that are not.

Table 4: Proposed Protocol for Defining Functional Relationships Between Watershed Imperviousness and Stream Quality

- General study design

  A systematic evaluation of stream quality for a population of 20 to 50 small subwatersheds that have different levels of watershed imperviousness. Selected field measurements are collected to represent key hydrological, morphological, water quality, habitat and biodiversity variables within each defined subwatershed. The population of subwatershed data is then statistically analyzed to define functional relationships between stream quality and imperviousness.

- Defining reference streams

  Up to 5 non-urban streams in same geo-hydrological region, preferably fully forested, or at least full riparian forest coverage along same length. Free of confounding NPS sources, imperviousness less than 5%, natural channel and good habitat structure.

- Basic Subwatershed Variables

  Watershed area, standard definition and method to calculate imperviousness, presence/absence of stormwater practices.

- Selecting subwatersheds

  Drainage areas from 100 to 500 acres, known level of imperviousness and age, free of confounding sources (active construction, mining, agriculture, or point sources). Select three random non-overlapping reaches (100 feet) for summer and winter sampling of selected variables in each of five key variables groups:

  1. Hydrology variables: summer dry weather flow, wetted perimeter, cross-sectional area of stream, peak annual storm flow (if gaged).
  2. Channel morphology variables: channel alteration, height, angle and extent of bank erosion, substrate embeddedness, sediment deposition, substrate quality.
  3. Water quality variables: summer water temperature, turbidity, total dissolved solids, substrate fouling index, EP toxicity test, wet weather bacteria, wet weather hydrocarbon.
  4. Habitat Variables: pool- riffle ratio, pool frequency, depth and substrate, habitat complexity, instream cover, riffle substrate quality, riparian vegetative cover, riffle embeddeness
  5. Ecological Variables: fish diversity, macroinvertebrate diversity, index of biological integrity, EPA Rapid Bioasessment Protocol, fish barriers, leaf pack processing rate.

Conclusion

Research has revealed that imperviousness is a powerful and important indicator of future stream quality and that significant degradation occurs at relatively low levels of development. The strong relationship between imperviousness and stream quality presents a serious challenge for urban watershed managers. It underscores the difficulty in maintaining urban stream quality in the face of development.

At the same time, imperviousness represents a common currency that can be measured and managed by planners, engineers and landscape architects alike. It links activities of the individual development site with its cumulative impact at the watershed scale. With further research, impervious cover can serve as an important foundation for more effective land use planning decisions.

References

Benke, A. E. Willeke, F. Parrish and D. Stites. 1981. *Effects of Urbanization on Stream Ecosystems.* Completion Report Project No. A-055-GA. Office of Water Research and Technology. US Dept. of Interior.

Black and Veatch. 1994. *Longwell Branch Restoration-Feasibility Study*. Vol 1. Carrol County, MD Office of Environmental Services. 220 pp.

Booth, D. 1991. "Urbanization and the Natural Drainage System-Impacts, Solutions and Prognoses. *Northwest Environmental Journal*. 7(1): 93-118.

Booth, D. and L. Reinelt. 1993. "Consequences of Urbanization on Aquatic Systems: Measured Effects, Degradation Thresholds, and Corrective Strategies." pp. 545-550 in *Proceedings Watershed '93 A National Conference on Watershed Management*. March 21-24, 1993. Alexandria, Virginia.

City of Olympia, 1994(a). *Impervious Surface Reduction Study: Technical and Policy Analysis—Final Report.* Public Works Department, Olympia, Washington. 83 pp.

City of Olympia, 1994(b). *Impervious Surface Reduction Study.* Draft Final Report. Public Works Department. City of Olympia, Washington. 183 pp.

Duda, A and K. Cromartie. 1982. "Coastal Pollution from Septic Tank DrainFields." *Journal of the Environmental Engineering Division* (ASCE). 108 (EE6).

Evett *et al.* 1994. *Effects of Urbanization and Land Use Changes on Low Stream Flow*. North Carolina Water Resources Research Institute, Report No. 284. 66 pp.

Galli, J. 1991. *Thermal Impacts Associated With Urbanization and Stormwater Management Best Management Practices*. Metropolitan Washington Council of Governments. Maryland Department of Environment. Washington, D.C. 188 pp.

Galli, J. 1993. *Rapid Stream Assessment Technique.* Metropolitan Washington Council of Governments. Washington, D.C.

Galli, J. 1994. Personal communication. Department of Environmental Programs. Metropolitan Washington Council of Governments. Washington, DC.

Garie, H and A. McIntosh. 1986. "Distribution of Benthic Macroinvertebrates in Streams Exposed to Urban Runoff." *Water Resources Bulletin* 22:447-458.

Gibson, G.,M. Barbour, J. Stribling and J. Karr. 1993. B*iological Criteria: Technical Guidance for Streams and Small Rivers.* US EPA Assessment and Watershed Protection Division, Washington, D.C.

Hollis, G. 1975. "The Effect of Urbanization on Floods of Different Recurrence Intervals." *Water Resources Res.* 11(3): 431-435.

Jones, R. and C. Clark. 1987. "Impact of Watershed Urbanization on Stream Insect Communities." American Water Resources Association. *Water Resources Bulletin.* 15(4)

Klein, R. 1979. "Urbanization and Stream Quality Impairment." American Water Resources Association. *Water Resources Bulletin.* 15(4).

Limburg, K and R. Schimdt. 1990. "Patterns of Fish Spawning in Hudson River Tributaries-Response to an Urban Gradient?" *Ecology* 71(4): 1231-1245.

Luchetti, G and R. Fuersteburg, 1993. *Relative Fish Use in Urban and Non-Urban Streams.* Proceedings Conference on Wild Salmon. Vancouver, British Columbia.

Macrae, C and J. Marsalek. 1992. *The Role of Stormwater in Sustainable Urban Development.* Proceedings Canadian Hydrology Symposium: 1992-Hydrology and Its Contribution to Sustainable Development, June 1992. Winnipeg, Canada.

Pedersen, E and M. Perkins. 1986. "The Use of Benthic Invertebrate Data for Evaluating Impacts of Urban Runoff." *Hydrobiologia*. 139: 13-22.

Plafkin, J. M. Barbour, K. Porter, S. Gross and R. Hughes. 1989. *Rapid Bioassessment Protocols for Use in Streams in Rivers: Benthic Macroinvertebrates and Fish*. US EPA Office of Water. EPA-444(440)/4-3901. Washington, D.C.

Planning & Zoning Center, Inc. 1992. *Grand Traverse Bay Region Development Guidebook.* Lansing Michigan. 125 pp.

Schueler, T. 1987. *Controlling Urban Runoff- A Practical Manual for Planning and Designing Urban Best Management Practices.* Metropolitan Washington Council of Governments. Washington, DC 240 pp.

Schueler, T. and John Galli. 1992. "Environmental Impacts of Stormwater Ponds." In *Watershed Restoration SourceBook*. Anacostia Restoration Team. Metropolitan Washington Council of Governments. Washington, DC. 242 pp.

Shaver, E., J. Maxted, G. Curtis and D. Carter. 1995. "Watershed Protection Using an Integrated Approach." In *Stormwater NPDES Related Monitoring Needs.* Engineering Foundation. American Society of Civil Engineers. Crested Butte, CO. August 7-12, 1994.

Simmons, D and R. Reynolds. 1982. "Effects of Urbanization on Baseflow of Selected South-Shore Streams, Long Island, NY." *Water Resources Bulletin.* 18(5): 797-805.

Steedman, R. J. 1988. "Modification and Assessment of an Index of Biotic Integrity to Quantify Stream Quality in Southern Ontario." *Canadian Journal of Fisheries and Aquatic Sciences.* 45:492-501.

Steward, C. 1983. *Salmonid Populations in an Urban Environment—Kelsey Creek, Washington*. Masters Thesis. University of Washington.

Taylor, B.L. 1993. *The Influences of Wetland and Watershed Morphological Characteristics and Relationships to Wetland Vegetation Communities.* Masters Thesis. Dept. of Civil Engineering. University of Washington, Seattle, WA.

Yoder C., 1991. "The Integrated Biosurvey as a Tool for Evaluation of Aquatic Life Use Attainment and Impairment in Ohio Surface Waters." In *Biological Criteria: Research and Regulation*. 1991.

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Lay Down at October 15, 2014 HAPC Meeting

I am a land owner in the Bridge Creek Watershed district. I am doing my part to protect this drinking water source on 350 acres up there by leaving it unfragmented. This is a huge cost to me and I feel that the city planners as well as all land owners have a responsibility to do the same to safeguard the future from cumulative impacts of development in our precious water source.

Strengthen these regulations. Do not cave in to pressure from the few to weaken these safeguards. Stand Strong !!! Once you open this door it will be hard to close. You cannot discriminate. Keep the regulations in tact!

Our Past wise Planning Commissions and Departments had the forethought and wherewithal to create The Bridge Creek Reservoir Watershed District. This District had full public meetings and participation designed for cost effective **prevention** of damage from human expansion in this watershed that provides our precious drinking water. It needs to remain intact.

Today our City Planning Department and Commission are asking for input to consider changes to our health and safety by weakening these drinking water safeguards. Bridge Creek Property owners have been barely notified in time to reply but the Homer Area Citizens who will pay the consequences of these negotiations…in their health and safety… are unaware of these weakened rules affecting their water quality.

Compromising our *drinking water* quality regulations is a serious gamble. If anything, regulations on this priority city service owned by all citizens requires strengthening never weakening to provide long term low cost water quality protection. **Prevention of cumulative damage** is the most cost effective means of providing clean water.

Our drinking water quality is not negotiable to a very few developers, realtors, or landowners pocketbooks. To weaken our well thought out water quality safeguards to placate a handful of people, steals the health and safety rights to clean clear chemical free healthy water from the thousands of tax paying Homer and outlying area citizens.

A subdivision like Kelly Ranch Estates was of prime concern when the District was created because it is located directly adjacent to the Bridge Creek that flows into our drinking water source. Subdivisions like this one without a city sewer system create the dilemma of raw sewage and siltation flowing into our drinking water source.

Relaxing water quality protections on so many developable lots is dangerous and will only increase the environmental and public health problems proven to be associated with sewage and siltation overflows.

The soils are extremely silty and nicks and damage caused silt and sewage to flow long distances. There is a history of these problems that must be understood by the planning commission.

This is serious to the health and welfare of all Homer Area citizens present and into the future. Sewage carries disease-causing microorganisms and pathogens that cause diarrhea, vomiting, respiratory and other infections, hepatitis, dysentery, and other chronic diseases such as cancer, arthritis and heart disease. they can be deadly for children, the elderly, and others with weakened immune systems, such as cancer patients.

Compromising our drinking water from lax rules is not cost effective. Prevention is our only proven tool to safeguard our water. We have these preventative regulations and they need to remain intact so our watershed is not damaged by a thousand cumulative cuts.

Just think! As we impair our watershed cut by cut…bigger impervious driveway here… larger garden with chemical fertilizers there…extra septic tank over here…ditching to drain a wetland there. Pharmaceuticals from sickness…oil from our driveways… each event removes the integrity from our water quality safeguards.

After a decade or two we will wonder… <u>What Happened???</u> Why is the operating expense to the water treatment plant going up. Why are more and more chemicals needed to settle silt and kill pathogens. Who is responsible for this?

Then… taxpayers not only get to pay with their health, healthcare costs, but with more tax dollars needed to rehabilitate the damage a handful of residents who got the ear of the present planning commission that caused cumulative damage to our critical watershed by weakening and compromising rules planned and designed by a long planned public process to protect us all through **prevention.**

The Planning Commission can help avoid cumulative deterioration in water quality by tabling these shortsighted ideas that serve only a few.

Water quality is not negotiable. This is a health and safety issue. To own land in this watershed is a big responsibility. It is an honour , and a privilege to contribute to the public good, not a means of lining someone's pocket.

Once you give special treatment for a small group you will be obliged to open this up to all Bridge Creek Property owners. Don't open this door!

It will be interesting to see who signs on to cutting these health and safety precautions of our most precious resource…our water. It will be important to keep track of names of those who compromised our rights to health and safety for a monetary gain by a select special interest few. The countless examples of watersheds compromised and the resulting **oops** can be easily googled for reference. Please do so to educate yourselves on this critically important issue.

Please don't gamble our precious water to feather a few nests at the expense of all our thousands of tax paying residents who rely on the city to perform this priority service.

Thank-you for your continued vigilance to protect the pure water quality of our Homer Area tax paying citizens.

With Kind Regards,

Nancy Hillstrand

RECEIVED

10/14/2014

CITY OF HOMER
PLANNING/ZONING

Public Health Effects of Inadequately Managed Stormwater Runoff

Stephen J. Gaffield, PhD, Robert L. Goo, Lynn A. Richards, MSES, MPA, and Richard J. Jackson, MD, MPH

Objectives. This study investigated the scale of the public health risk from stormwater runoff caused by urbanization.

Methods. We compiled turbidity data for municipal treated drinking water as an indication of potential risk in selected US cities and compared estimated costs of waterborne disease and preventive measures.

Results. Turbidity levels in other US cities were similar to those linked to illnesses in Milwaukee, Wis, and Philadelphia, Pa. The estimated annual cost of waterborne illness is comparable to the long-term capital investment needed for improved drinking water treatment and stormwater management.

Conclusions. Although additional data on cost and effectiveness are needed, stormwater management to minimize runoff and associated pollution appears to make sense for protecting public health at the least cost. (*Am J Public Health.* 2003;93:1527–1533)

Residents in the United States generally can depend on safe water for drinking, food production, and recreation, thanks to effective water treatment and protective environmental policies. Despite these safeguards, waterborne illnesses are prevalent and may increase because of the strain of climate change, population growth, and changing land use.[1] Expansion of urban areas is creating more impervious surfaces, such as roofs, roads, and parking lots, that collect pathogens, metals, sediment, and chemical pollutants and quickly transmit them to receiving waters during rain and snowmelt events. This nonpoint source pollution is one of the major threats to water quality in the United States[2] and is linked to chronic and acute illnesses from exposure through drinking water, seafood, and contact recreation. Impervious surfaces also lead to pooling of stormwater, increasing potential breeding areas for mosquitoes, the disease vectors for dengue hemorrhagic fever, West Nile virus, and other infectious diseases.

Traditional strategies to manage stormwater and treat drinking water require large infrastructure investments and face difficult technical challenges. Reducing stormwater runoff and associated nonpoint source pollution is a potentially valuable component of an integrated strategy to protect public health at the least cost.

WATERBORNE DISEASE

Acute illnesses can result from consuming water contaminated with protozoan oocysts, viruses, and bacteria. Between 1991 and 2000, 123 documented outbreaks of waterborne illness in 30 states were linked to pathogens or involved acute gastrointestinal illnesses of unknown etiology (Figure 1).[3–7] Pathogens currently impair 5529 US water bodies (Figure 2) and are the second leading cause of impairment, following sediment.[8]

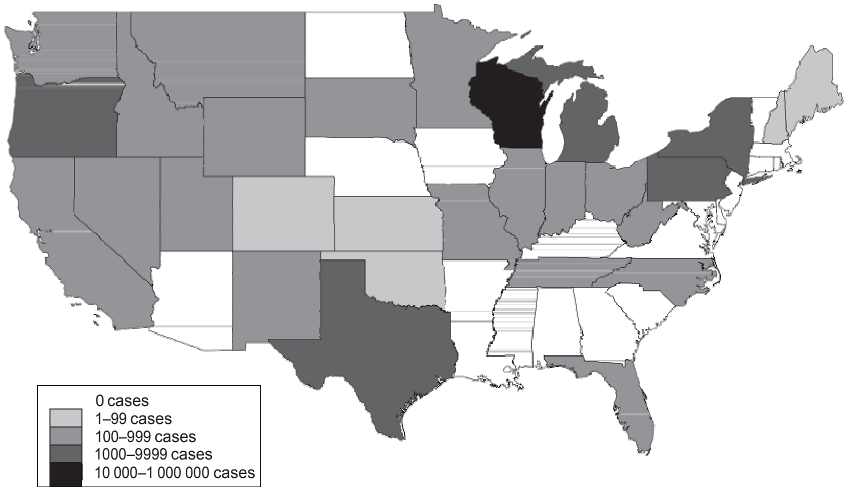
Children, the elderly, pregnant women, and the immunocompromised—20% of the US population—are at the greatest risk for serious illness and mortality from waterborne pathogens.[9] Outbreaks of cryptosporidiosis in Milwaukee, Wis, in 1993 and Las Vegas, Nev, in 1994 caused at least 70 fatalities among the immunocompromised.[4,10–12]

It is widely recognized that the vast majority of waterborne disease cases go unreported because of difficulties in diagnosing the cause of illness. Approximately 99 million people in the United States have acute gastrointestinal illnesses each year, at a cost of billions of dollars,[13] and 6% to 40% of these illnesses may be caused by contaminated drinking water.[1,14,15] Exposure to *Cryptosporidium* is common; 17% to 32% of people tested have evidence of infection by young adulthood.[16]

Drinking water outbreaks have been linked to runoff; more than half of the documented waterborne disease outbreaks since 1948 have followed extreme rainfalls.[17] Spring rains and snowmelt preceded the Milwaukee *Cryptosporidium* outbreak and may have played a role in transport of the oocysts.[6] Urban and suburban streets, parking lots, and lawns generate large loads of bacteria in stormwater,[18–20] and urban runoff is responsible for an estimated 47% of the pathogen contamination of Long Island Sound.[21] Stormwater drainage pipelines and channels accumulate sediment and block sunlight, inhibiting natural bacteria die-off and creating a bacterial reservoir,[22,23] and combined storm and sanitary sewer systems discharge untreated sewage into receiving waters when runoff volumes overwhelm their treatment capacity.

Inflows of runoff to surface water bodies, indicated by increased turbidity from suspended soil particles eroded from the landscape, are associated with elevated concentrations of bacteria, *Giardia*, *Cryptosporidium*, and other microorganisms.[24,25] Small increases in the turbidity of treated drinking water have been linked to increased occurrence of acute gastrointestinal illnesses among children and the elderly in Milwaukee and Philadelphia, Pa, even though the water is in compliance with Environmental Protection Agency standards.[26–28]

Fecal coliform bacteria in surface waters commonly exceed standards for recreation,[29] and exposure to bacteria and parasites from swimming and other forms of recreation in water contaminated with urban runoff has caused numerous cases of illness, including ear and eye discharges, skin rashes, and gastrointestinal problems.[30–32] Consumption of seafood from contaminated waters is linked to diarrheal and paralytic illnesses caused by the hepatitis A and Norwalk viruses, *Vibrio* species, and marine biotoxins formed by algal blooms.[31,33–36] Excess nitrogen from urban



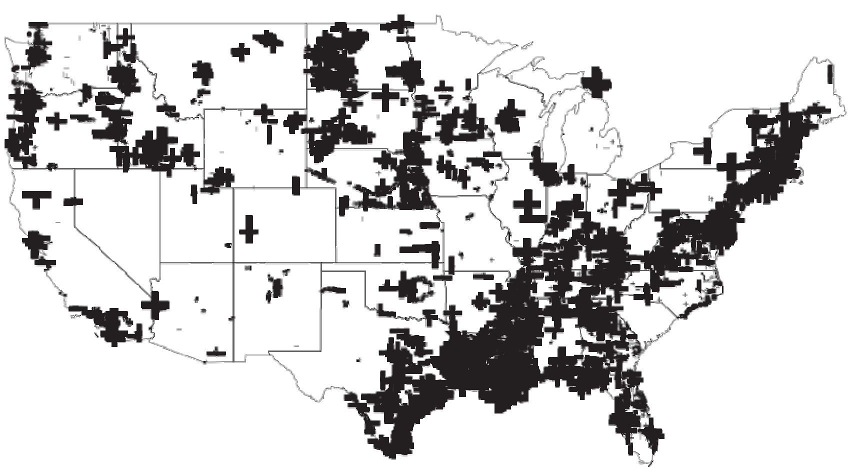
Note. Wisconsin reported the maximum number of cases, with 403 000 caused by the cryptosporidiosis outbreak of 1993.
Source. Compiled from Centers for Disease Control and Prevention data.[3–7]

FIGURE 1—Reported waterborne illnesses linked to pathogens or involving gastrointestinal illnesses of unknown etiology, 1991–2000.

and agricultural sources exacerbates harmful algal blooms.[37] Major sources of nitrogen from urban and suburban areas may include fertilizers carried by stormwater, vehicle exhaust, and septic systems.[38,39]

Nitrogen also poses direct health threats. Exposure to nitrate in drinking water increases the risk of methemoglobinemia, causing shortness of breath and blueness of the skin, especially for infants.[40,41] Consumption of water with elevated nitrate is also suspected to increase miscarriage risk.[42]

Various pollutants are commonly found in urban and suburban stormwater. Runoff from roofs, roads, and parking lots can contain significant concentrations of copper, zinc, and lead,[19,38] which can have toxic effects in humans. Insecticides occur widely in sediment and fish in urban streams at levels considered harmful to wildlife,[43] raising concerns about carcinogenic effects and disruption of hormonal systems in humans.[44] Increased traffic volume in recent decades has resulted in higher concentrations of polyaromatic hydrocarbons—known human carcinogens—in urban lake sediments, with concentrations commonly exceeding levels set to protect aquatic ecosystems.[45]



Source. Compiled from US Environmental Protection Agency data.[8]

FIGURE 2—Pathogen-impaired water bodies, 1998–2000.

DRINKING WATER TREATMENT

Community drinking water supplies are commonly disinfected with chlorine and, if the source is surface water, filtered to remove sediment and associated pollutants. Several common microorganisms, including *Cryptosporidium*, are resistant to treatment with chlorine and filtration,[46] although the effectiveness of filters varies with their pore size. Suspended sediment in source waters further reduces the effectiveness of chlorine. A 1995 study found that 13% of the samples of drinking water filtered and treated with chlorine still contained *Cryptosporidium* oocysts.[47] Ozone is increasingly being used for disinfection instead of or in addition to chlorine. High ozone doses can inactivate *Giardia* and *Cryptosporidium*; however, neutralizing the ozone after treatment presents technical difficulties, and addition of ozone to water containing bromide can form bromate, a potential human carcinogen.[48]

The need for disinfection must be weighed against growing evidence of carcinogenic and other health effects related to disinfection byproducts. Trihalomethanes and other disinfection byproducts form when chlorine reacts with organic carbon associated with sediment or produced by algal and bacterial growth, which can be enhanced by nitrogen and phosphorous in runoff.[49] The Environmental Protection Agency estimates that ingestion of disinfection byproducts in drinking water leads to 1100 to 9300 cases of bladder cancer each year,[50] and trihalomethanes are linked to neural tube defects, small size for gestational age, and spontaneous abortions.[51]

Approximately 42 million people in rural and suburban areas use their own private water supplies, typically shallow groundwater wells that are not covered by the Safe Drinking Water Act and are rarely treated or monitored.[52] Concerns include cross-contamination from runoff and surface water and contamination by nitrates and pathogens from septic systems.

EFFECTS OF COMMUNITY DESIGN

Community design has a major effect on stormwater volumes and quality, as well as treatment methods and costs. The total area of impervious surfaces in a community is 1 of the most common measures used to assess the effects of community design on stormwater runoff.[53] Also important is the degree of connection between impervious surfaces and the storm drainage system; surfaces that drain directly to vegetated areas produce less runoff and are considered to have a lower effective impervious area.

Urbanization of the landscape adds to strain on water resources by expanding the area covered by impervious surfaces that shed virtually all rainfall and snowmelt. Hydrologic models predict large increases in runoff for urbanizing areas,[54,55] with runoff volume increasing linearly with impervious surface area.[56] Long-term stream-flow monitoring has shown that development leads to higher flood peaks[57] and to increases in annual runoff volumes of 2 to 4 times previous levels for suburban areas and 15 times previous levels for highly urban areas.[58,59]

Increased runoff volume generates greater pollutant loads.[60] In response to an 18% increase in urban area in a watershed near Indianapolis, Ind, between 1973 and 1991, annual average runoff volume increased by 80%, and average annual loads for lead, copper, and zinc increased by more than 50%.[61] High proportions of urban land cover and steep slopes—predictors of high runoff volumes—correspond with high fecal coliform levels in South Carolina watersheds.[62] Elevated fecal coliform levels also have been detected in suburban streams.[63]

Although low-density development with large lawns leads to a low proportion of impervious cover within individual lots, the total impervious surface area of low-density residential and commercial developments, on the regional scale, is typically much larger than that of higher-density developments.[64,65] This high proportion of impervious surface area is largely a result of roads and parking lots, which can account for more than 60% of a low-density development's impervious area.[66] Although large lawns might seem capable of absorbing runoff from adjacent surfaces, they are typically compacted by construction equipment and can generate up to 90% as much runoff as pavement.[67,68] Runoff measured from suburban developments has been shown to be 1.5 to 4 times greater than that from rural areas,[69,70] although low-density development may produce less runoff than do some intensive agricultural land uses.[71]

Moreover, construction of low-density developments disturbs the soil over larger land areas, accelerating transport of sediment and associated pollutants into water bodies. Stripping the protective vegetation cover from construction sites accelerates soil erosion to a rate up to 40 000 times higher than before the soil was disturbed.[72] During brief periods of active construction, sediment yield from watersheds can increase 5-fold, with additional deposition in stream channels providing a continual sediment source during subsequent storms.[73] This accumulated sediment can harbor large populations of bacteria and other pathogens.[74]

There is widespread concern that increased runoff from impervious surfaces contributes to the depletion of groundwater aquifers. Unfortunately, few detailed studies of urban groundwater recharge have been performed to evaluate this concern. Leaks from aging water distribution networks and infiltration in stormwater ponds and channels may add appreciably to aquifer recharge.[75] However, infiltration ponds have a high failure rate because of fine sediment that settles to the bottom and forms a hydraulic barrier,[76] and improvements in construction materials for water pipelines probably lead to reduced leakage in new developments.[77] Nearly half of the US population drinks groundwater from wells,[52] and widespread drops in groundwater levels have contributed to water quality problems, including increased arsenic concentrations.[78]

METHODS

Because turbidity is an indicator of runoff and was associated with increased illness in Milwaukee and Philadelphia,[26–28] we compiled turbidity data for treated drinking water of selected cities in 2001 for comparison. We obtained this information from annual consumer confidence reports published by each water utility. Many of these systems reported turbidity values for water mixed from multiple sources and treatment facilities.

An important consideration in deciding how to address waterborne illness is the cost associated with different options. Unfortunately, available data are inadequate to fully assess these costs. In this article, we present estimates of some of the costs associated with (1) managing current levels of waterborne illness, (2) improving drinking water treatment, and (3) improving stormwater management. Although incomplete, such estimates illustrate the magnitude of these costs and underscore important unanswered questions.

We estimated the annual cost of gastrointestinal illnesses related to drinking water by multiplying the estimated cost of all infectious gastrointestinal illnesses for 1985[13] by the fraction of these illnesses (6%–40%) attributed to drinking water in the literature.[1] Cost estimates for drinking water treatment and stormwater management were taken from Environmental Protection Agency surveys of 20-year capital investment needs.[79,80] We did not extrapolate the annual cost of illness over the same 20-year period, because this estimate was based on data from only 1 year. All costs were converted to 2002 dollars.

RESULTS

Table 1 lists annual minimum, mean, and maximum turbidity values based on daily samples of treated drinking water for selected cities. All of these systems were in compliance with the Environmental Protection Agency requirements in effect at that time that no sample exceed a turbidity of 5 nephelometric turbidity units and that no more than 5% of daily samples show turbidity greater than 0.5 nephelometric turbidity unit. In 2002, these standards were reduced to 1 nephelometric turbidity unit and 0.3 nephelometric turbidity unit, respectively.

The low and high estimates of the annual cost of gastrointestinal illnesses related to drinking water (Table 2) differ by nearly a

TABLE 1—Turbidity Values for Treated Drinking Water Reported by Selected Cities for 2001

City/Treatment System	Drinking Water Turbidity (NTU) Minimum	Maximum	Mean
Ann Arbor, Mich	NR	0.2	NR
Atlanta, Ga	NR	> 0.5	NR
Austin, Tex	0.01	0.34	0.08
Baltimore, Md			
Ashburton filtration plant	NR	0.39	NR
Montebello filtration plants	NR	0.41	NR
Chicago, Ill	NR	NR	0.34
Corvallis, Ore	0.02	0.08	0.04
Dallas, Tex	0.04	0.2	0.08
Denver, Colo			
Marston filtration plant	< 0.05	0.07	0.04
Foothills filtration plant	0.04	0.05	0.04
Moffat filtration plant	0.04	0.07	0.05
Detroit, Mich	NR	0.48	NR
Houston, Tex, main	< 0.01	0.5	0.07
Los Angeles, Calif			
Los Angeles Aqueduct filtration plant	0.1	0.37	0.12
Diemer filtration plant	0.05	0.07	0.06
Weymouth filtration plant	0.06	0.08	0.07
Milwaukee, Wis	0.06	0.23	0.08
New York, NY			
Catskill–Delaware system	0.8	1.7	1.1
Croton system	1.3	1.6	1.4
Philadelphia, Pa	NR	0.08	0.06
Seattle, Wash			
Cedar system	0.3	3.9	0.8
Tolt system	0.04	0.3	0.07
Washington, DC	NR	0.19	NR

Note. NTU = nephelometric turbidity unit; NR = not reported.

TABLE 2—Comparison of Costs of Options for Addressing Waterborne Illness

Option	Estimate	Cost, in Billions of 2002 Dollars	Source
Continue to manage waterborne illnesses	Annual cost of waterborne gastrointestinal illnesses	2.1–13.8[a]	Estimate of total cost of endemic gastrointestinal illness in 1985[13] and range of these illnesses attributed to drinking water[1]
Improve drinking water treatment	20-year capital needs to meet current and proposed drinking water standards	33.0[b]	1999 Drinking Water Infrastructure Needs Survey[79]; "regulatory needs" for compliance with current and future regulations
Improve stormwater management	20-year capital needs for runoff control	9.3[c]	1996 Clean Water Needs Survey[80]; categories VI (stormwater) and VIID (urban runoff)

[a]Adjusted for inflation by multiplying by factor of 1.50.
[b]Adjusted for inflation by multiplying by factor of 1.06.
[c]Adjusted for inflation by multiplying by factor of 1.11.

factor of 10 because of uncertainty in identifying the cause of illness. These estimates do not include other acute effects, chronic illnesses, or illnesses related to recreation or consumption of contaminated seafood or produce. The higher estimate is comparable to the 20-year capital costs for enhanced drinking water treatment and stormwater management. Operation and maintenance over the 20-year period are not included in these estimates; however, a reasonable assumption is

investment.[81,82]

DISCUSSION

Although it is highly likely that Figure 1 greatly underestimates the burden of disease caused by waterborne pathogens, it does indicate widespread occurrence of such disease. Because of underreporting issues and the poor geographic resolution of the state-level illness data, it is difficult to directly compare Figures 1 and 2.

The turbidity of drinking water in many US cities (Table 1) is similar to the level of turbidity linked to illnesses in Milwaukee and Philadelphia (where the mean turbidity was < 0.2 nephelometric turbidity unit).[26–28] Although these data alone are insufficient to define the level of risk, they underscore the need for additional research into the complex relations between turbidity, pathogen loads, drinking water treatment, and illness. Assessment of risk and early warning of contamination would be greatly aided by more rapid and accurate testing methods for microbiological contaminants.[83]

Given the limited information in Table 2, the costs of drinking water treatment and stormwater management appear reasonable compared with the burden of waterborne illness. The economic benefits of drinking water treatment have been established previously.[84]

ness of stormwater management options as well as on the true cost of waterborne illness are needed to make fully informed decisions.

Conventional urban stormwater management requires a large investment in infrastructure. For example, the Milwaukee Metropolitan Sewage District has reduced, but not eliminated, combined sewer overflows since 1994 by spending $716 million to construct a tunnel to store excess stormwater during runoff events, allowing it to be treated later.[85] Consequently, it makes sense to use alternative strategies that reduce the volume and improve the quality of stormwater. Planning on the regional scale that integrates community design and watershed function can reduce stormwater volumes and effects. On the local scale, further reduction can be achieved through compact site design and best management practices that remove pollutants, detain stormwater, and reduce runoff volume by enhancing infiltration into the soil.

Watershed planning strategies that effectively protect water quality include maintaining vegetated buffer strips and setback distances of at least 150 m for impervious areas along water bodies[63,86] and preserving forests and other highly pervious land covers.[87] New York City has chosen to spend $1.4 billion over 10 years as part of a strategy to protect its Catskill–Delaware water supply by purchasing land as a buffer against development, thus avoiding the need for a filtration plant that would cost $6 billion to construct and would have an annual operating cost of $300 million.[88,89]

Compact site designs include narrow streets, reduced parking requirements, mixed land uses, increased residential densities, and open space. The city of Olympia, Wash, determined that a 20% reduction in impervious area would not require exceptional changes.[66] A stormwater ordinance passed by the city of Columbus, Ohio, includes reducing street widths and commercial parking to minimize impervious surfaces and enhance open space.[90] Runoff simulations of proposed community designs suggest that a compact development with significant open space may generate only half the increased stormwater volume generated by a conventional, large-lot development.[91]

Best management practices can reduce but not eliminate pollutant loadings of common stormwater pollutants. Designs that collect runoff and allow it to infiltrate the soil have the highest documented pollutant-removal efficiency, eliminating nearly all lead, zinc, and solids and more than 50% of total nitrogen and phosphorus. Ponds and wetlands, which allow contaminants to settle out of the water column or be broken down by sunlight and biological activity, can remove more than 70% of bacteria but are less effective for other pollutants. Drainage ditches and swales appear to have very limited pollutant-removal capabilities.[92] Pollutant modeling indicates that street sweeping once a week on highways and every 3 days in residential areas removes 10% to 60% of solids and nutrients.[93] Modern street sweepers that use vacuum systems may result in higher and more consistent pollutant-removal effectiveness, although potential negative side effects, such as air and noise pollution, also must be considered. Managing urban pet and wildlife waste may reduce pathogen loads, although more research on parasite and bacteria infection rates in animals is needed.[83]

Low-impact development techniques are gaining popularity for supplementing traditional best management practices and reducing infrastructure needs. Low-impact development measures route runoff from impervious surfaces to natural or constructed features where it can infiltrate the soil. Connecting roof drains to a yard, garden, or infiltration trench can double the amount of precipitation that infiltrates the soil.[94] Diverting roof downspouts from sanitary sewers to yards in a Michigan community reduced storm flows in sewers by 25% to 62%, resulting in cost savings that matched the cost of the conversion in only 2 months.[95] Buildings with green roofs (roofs covered with soil and live vegetation to absorb precipitation) have been used for years in Europe and have been successfully constructed in the United States.

Protecting public health by reducing urban stormwater runoff and associated nonpoint source pollution makes sense as a complement to water treatment infrastructure and health care interventions. In fact, stormwater management needs to be integrated into a comprehensive water management scheme that addresses water supply and sewage treatment. We believe that such integrated programs are necessary to adequately protect public health at the lowest cost. ■

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This article was accepted May 8, 2003.

Contributors

S.J. Gaffield led the design and implementation of the study and the writing of the article. R.L. Goo helped to conceptualize ideas, plan the analysis, and write the article. L.A. Richards assisted with the literature review, study design, and writing of the article. R.J. Jackson conceived of this article and assisted with planning and writing.

Acknowledgments

We wish to thank Kenneth W. Potter, of the University of Wisconsin, Madison, for providing helpful discussion of infiltration and groundwater recharge and Edward H. Chu, of the US Environmental Protection Agency, for providing insight and assistance with the economic analysis.

Human Participant Protection

No human participants were involved in this study.

References

1. Levin RB, Epstein PR, Ford TE, Harrington W, Olson E, Reichard EG. US drinking water challenges in the twenty-first century. *Environ Health Perspect.* 2002; 110(suppl 1):43–52.

2. *National Water Quality Inventory: 2000 Report.* Washington, DC: US Environmental Protection Agency; 2000. Report EPA-841-R-02-001.

3. Moore AC, Herwaldt BL, Craun GF, Calderon RL, Highsmith AK, Juranek DD. Surveillance for waterborne disease outbreaks—United States, 1991–1992. *MMWR CDC Surveill Summ.* 1993;42(SS-5):1–22.

4. Kramer MH, Herwaldt BL, Craun GF, Calderon RL, Juranek DD. Surveillance for waterborne-disease outbreaks—United States, 1993–1994. *MMWR CDC Surveill Summ.* 1996;45(SS-1):1–33.

5. Levy DA, Bens MS, Craun GF, Calderon RL, Herwaldt BL. Surveillance for waterborne-disease outbreaks—United States, 1995–1996. *MMWR CDC Surveill Summ.* 1998;47(SS-5):1–34.

6. Barwick RS, Levy DA, Craun GF, Beach MJ, Calderon RL. Surveillance for waterborne-disease outbreaks—United States, 1997–1998. *MMWR CDC Surveill Summ.* 2000;49(SS-4):1–35.

7. Lee SH, Levy DA, Craun GF, Beach MJ, Calderon RL. Surveillance for waterborne-disease outbreaks—United States, 1999–2000. *MMWR CDC Surveill Summ.* 2002;51(SS-8):1–28.

8. US Environmental Protection Agency. National Section 303(d) List Fact Sheet [report online]; 2002. Available at: http://oaspub.epa.gov/waters/national_rept.control. Accessed December 13, 2002.

9. Gerba CP, Rose JB, Haas CN. Sensitive populations: who is at the greatest risk? *Int J Food Microbiol.* 1996;30(1–2):113–123.

10. MacKenzie WR, Hoxie NJ, Proctor ME, et al. A massive outbreak in Milwaukee of Cryptosporidium infection transmitted through public water supply. *N Engl J Med.* 1994;331:161–167.

11. Hoxie NJ, Davis JP, Vergeront JM, Nashold RD, Blair KA. Cryptosporidiosis-associated mortality following a massive waterborne outbreak in Milwaukee, Wisconsin. *Am J Public Health.* 1997;87:2032–2035.

12. Goldstein ST, Juranek DD, Ravenholt O, et al. Cryptosporidiosis: an outbreak associated with drinking water despite state-of-the-art water treatment. *Ann Intern Med.* 1996;124:459–468.

13. Garthright WE, Archer DL, Kvenberg JE. Estimates of incidence and costs of intestinal infectious diseases in the United States. *Public Health Rep.* 1988; 103:107–115.

14. Payment P, Richardson L, Siemiatycki J, Dewar R,

Edwardes M, Franco E. A randomized trial to evaluate the risk of gastrointestinal disease due to consumption of drinking water meeting current microbiological standards. *Am J Public Health.* 1991;81:703–708.

15. Chute CG, Smith RP, Baron JA. Risk factors for endemic giardiasis. *Am J Public Health.* 1987;77: 585–587.

16. Guerrant RL. Cryptosporidiosis: an emerging, highly infectious threat. *Emerg Infect Dis.* 1997;3: 51–57.

17. Curriero FC, Patz JA, Rose JB, Lele SD. The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948–1994. *Am J Public Health.* 2001;91:1194–1199.

18. Olivieri VP, Kruse CW, Kawata K. Selected pathogenic microorganisms contributed from urban watersheds. In: Correll DL, ed. *Watershed Research in North America: A Workshop to Compare Results.* Vol 2. Edgewater, Md: Smithsonian Institution, Chesapeake Bay Center for Environmental Studies; 1977:635–661.

19. Bannerman RT, Owens DW, Dodds RB, Hornewer NJ. Sources of pollutants in Wisconsin stormwater. *Water Sci Technol.* 1993;28(3–5): 241–259.

20. Young KD, Thackston EL. Housing density and bacterial loading in urban streams. *J Environ Eng.* 1999;125:1177–1180.

21. *Long Island Sound Study: Summary of the Comprehensive Conservation and Management Plan.* Stamford, Conn: US Environmental Protection Agency; 1994. Report EPA-842-S-94-001.

22. Occoquan Watershed Monitoring Lab. *Fecal Coliform Counts in Stream Sections in Below-Ground Culverts: A Report Submitted to the Northern Virginia Regional Commission.* Manassas: Virginia Polytechnic Institute and State University; 2002.

23. Marino RP, Gannon JJ. Survival of fecal coliforms and fecal streptococci in storm drain sediment. *Water Res.* 1991;25:1089–1098.

24. Atherholt TB, LeChevallier MW, Norton WD, Rosen JS. Effect of rainfall on Giardia and Cryptosporidium. *J Am Water Works Assoc.* 1998;90(9):66–80.

25. Gannon JJ, Busse MK. E. coli and enterococci levels in urban stormwater, river water and chlorinated treatment plant effluent. *Water Res.* 1989;23: 1167–1176.

26. Morris RD, Naumova EN, Levin R, Munasinghe RL. Temporal variation in drinking water turbidity and diagnosed gastroenteritis in Milwaukee. *Am J Public Health.* 1996;86:237–239.

27. Schwartz J, Levin R, Hodge K. Drinking water turbidity and pediatric hospital use for gastrointestinal illness in Philadelphia. *Epidemiology.* 1997;8:615–620.

28. Schwartz J, Levin R, Goldstein R. Drinking water turbidity and gastrointestinal illness in the elderly of Philadelphia. *J Epidemiol Community Health.* 2000;54: 45–51.

29. *Selected Findings and Current Perspectives on Urban and Agricultural Water Quality by the National Water-Quality Assessment Program.* Reston, Va: US Geological Survey; 2001. Fact Sheet FS-047–01.

30. Dufour AP. *Freshwater Recreational Water Quality and Swimming-Associated Illnesses: Proceedings of the 2nd National Symposium on Municipal Wastewater Disinfection.* Cincinnati, Ohio: US Environmental Protection Agency; 1983. Report EPA-600-*-9-83-009.

31. Rose JB, Epstein PR, Lipp EK, Sherman BH, Bernard SM, Patz JA. Climate variability and change in the United States: potential impacts on water- and foodborne diseases caused by microbiologic agents. *Environ Health Perspect.* 2001;109(suppl 2):211–221.

32. Haile RW, Alamillo J, Barrett K, et al. *An Epidemiological Study of Possible Adverse Health Effects of Swimming in Santa Monica Bay: Final Report.* Santa Monica, Calif: Santa Monica Bay Restoration Project; 1996.

33. Craun GF. Waterborne disease outbreaks in the United States of America: causes and prevention. *World Health Stat Q.* 1992;45:192–199.

34. Centers for Disease Control and Prevention. Paralytic shellfish poisoning—Massachusetts and Alaska, 1990 [published erratum appears in *MMWR Morb Mortal Wkly Rep.* 1991;40(14):242]. *MMWR Morb Mortal Wkly Rep.* 1991;40(10):157–161.

35. Centers for Disease Control and Prevention. Multistate outbreak of viral gastroenteritis related to consumption of oysters—Louisiana, Maryland, Mississippi, and North Carolina. *MMWR Morb Mortal Wkly Rep.* 1993;42(49):945–948.

36. Epstein PR, Ford TE, Colwell RR. Marine ecosystems. *Lancet.* 1993;342:1216–1219.

37. National Research Council. *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution.* Washington, DC: National Academy Press; 2000.

38. Whipple W, Grigg S, Gizzard T, Randall CW, Shubinski RP, Tucker LS. *Stormwater Management in Urbanizing Areas.* Englewood Cliffs, NJ: Prentice-Hall; 1983.

39. Wernick BG, Cook KE, Schreier H. Land use and streamwater nitrate-N dynamics in an urban-rural fringe watershed. *J Am Water Resources Assoc.* 1998; 34:639–650.

40. Integrated Risk Information System (IRIS) [database online]. Cincinnati, Ohio: US Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment. Available at: http://www.epa.gov/ngispgm3/iris/index.html. Accessed December 9, 2002.

41. *National Primary Drinking Water Regulations Technical Fact Sheets.* Washington, DC: US Environmental Protection Agency, Office of Water, Office of Ground Water and Drinking Water; 1999.

42. Centers for Disease Control and Prevention. Spontaneous abortions possibly related to ingestion of nitrate contaminated well water—LaGrange County, Indiana, 1991–1994. *MMWR Morb Mortal Wkly Rep.* 1996;45(26):569–572.

43. *The Quality of Our Nation's Waters—Nutrients and Pesticides.* Reston, Va: US Geological Survey; 1999. Circular 1225.

44. National Research Council. *Hormonally Active Agents in the Environment.* Washington, DC: National Academy Press; 1999.

45. Van Metre PC, Mahler BJ, Furlong ET. Urban sprawl leaves its PAH signature. *Environ Sci Technol.* 2000;34:4064–4070.

46. Steiner TS, Thielman NM, Guerrant RL. Protozoal agents: what are the dangers for the public water supply? *Annu Rev Med.* 1997;48:329–340.

47. LeChevallier MW, Norton WD. Giardia and Cryptosporidium in raw and finished water. *J Am Water Works Assoc.* 1995;87(9):54–68.

48. National Research Council. *Identifying Future Drinking Water Contaminants.* Washington, DC: National Academy Press; 1999.

49. National Research Council. *Watershed Management for Potable Water Supply: Assessing the New York City Strategy.* Washington, DC: National Academy Press; 2000.

50. *Quantification of Cancer Risk From Exposure to Chlorinated Water.* Washington, DC: US Environmental Protection Agency, Office of Science and Technology, Office of Water; 1998.

51. Bove F, Shim Y, Zeitz P. Drinking water contaminants and adverse pregnancy outcomes: a review. *Environ Health Perspect.* 2002;110(suppl 1):61–74.

52. Solley WB, Pierce RR, Perlman HA. *Estimated Use of Water in the United States in 1995.* Reston, Va: US Geological Survey; 1998. Circular 1200.

53. Arnold CL, Gibbons CJ. Impervious surface coverage: the emergence of a key environmental indicator. *J Am Plann Assoc.* 1996;62:243–258.

54. Brun SE, Band LE. Simulating runoff behavior in an urbanizing watershed. *Comput Environ Urban Syst.* 2000;24:5–22.

55. Grove M, Harbor J, Engel B, Muthukrishnan S. Impacts of urbanization on surface hydrology, Little Eagle Creek, Indiana, and analysis of L-THIA model sensitivity to data resolution. *Phys Geography.* 2001; 22:135–153.

56. Bhaduri B, Minner M, Tatalovich S, Harbor J. Long-term hydrologic impact of urbanization: a tale of two models. *J Water Resources Plann Manage.* 2001; 127:13–19.

57. *Urbanization and Streams: Studies of Hydrologic Impacts.* Washington, DC: US Environmental Protection Agency; 1997. Report EPA-841-R-97-009.

58. Spinello AG, Simmons DL. *Base Flow of 10 South-Shore Streams, Long Island, New York, 1976–85, and the Effects of Urbanization on Base Flow and Flow Duration.* Reston, Va: US Geological Survey; 1992. Water-Resources Investigations Report 90-4205.

59. Burges SJ, Wigmosta MS, Meena JM. Hydrological effects of land-use change in a zero-order catchment. *J Hydrologic Eng.* 1998;3(2):86–97.

60. Charbeneau RJ, Barrett ME. Evaluation of methods for estimating stormwater pollutant loads. *Water Environ Res.* 1998;70:1295–1302.

61. Bhaduri B, Harbor J, Engel B, Grove M. Assessing watershed-scale long-term hydrologic impacts of land-use change using a GIS–NPS model. *Environ Manage.* 2000;26:643–658.

62. Smith JH, Wickham JD, Norton D, Wade TG, Jones KB. Utilization of landscape indicators to model potential pathogen impaired waters. *J Am Water Resources Assoc.* 2001;37:805–814.

63. Mallin MA, Wheeler TL. Nutrient and fecal coliform discharge from coastal North Carolina golf courses. *J Environ Qual.* 2000;29:979–986.

64. Zielinski J. The benefits of better site design in residential subdivisions. In: Schueler TR, Holland HK, eds. *The Practice of Watershed Protection.* Ellicott City, Md: Center for Watershed Protection; 2000:11–24.

65. Zielinski J. The benefits of better site design in commercial development. In: Schueler TR, Holland HK, eds. *The Practice of Watershed Protection.* Ellicott City, Md: Center for Watershed Protection; 2000: 25–34.

66. *Impervious Surface Reduction Study: Technical and Policy Analysis: Final Report.* Olympia, Wash: City of Olympia, Public Works Department; 1995.

67. Legg A, Bannerman R, Panuska J. *Variation in the Relation of Rainfall to Runoff From Residential Lawns in Madison, Wisconsin, July and August, 1995.* Madison, Wis: US Geological Survey; 1996. Water-Resources Investigation Report 96-4194.

68. Wignosta M, Burges S, Meena J. *Modeling and Monitoring to Predict Spatial and Temporal Hydrological Characteristics in Small Catchments.* Seattle: University of Washington, Dept of Civil Engineering; 1994. Water Resources Series Technical Report 137.

69. Buttle JM, Xu F. Snowmelt runoff in suburban environments (Ontario, Canada). *Nordic Hydrology.* 1988; 19:19–40.

70. Stephenson D. Comparison of the water balance for an undeveloped and a suburban catchment. *Hydrological Sci J.* 1994;39:295–307.

71. Liu AJ, Tong ST, Goodrich JA. Land use as a mitigation strategy for the water-quality impacts of global warming: a scenario analysis on two watersheds in the Ohio River Basin. *Environ Eng Policy.* 2000;2:65–76.

72. Harbor J. Engineering geomorphology at the cutting edge of land disturbance: erosion and sediment control on construction sites. *Geomorphology.* 1999; 31(1–4):247–263.

73. Roberts WP, Pierce JW. Deposition in Upper Patuxent Estuary, Maryland, 1968–1969. *Estuarine Coastal Shelf Sci.* 1976;4(3):267–280.

74. Schillinger JE, Gannon JJ. Bacterial adsorption and suspended particles in urban stormwater. *J Water Pollut Control Fed.* 1985;57:384–389.

75. Lerner DN. Identifying and quantifying urban recharge: a review. *Hydrogeology J.* 2002;10:143–152.

76. Lindesy G, Roberts L, Page W. Inspection and maintenance of infiltration facilities. *J Soil Water Conservation.* 1992;47:481–486.

77. Rajani B, McDonald S, Felio G. *Water Mains Break Data on Different Pipe Materials for 1992 and 1993.* Ottawa, Ontario: Nation Research Council of Canada Report; 1995. Client Report CR-7019.1.

78. Schreiber ME, Simo JA, Freiberg PG. Stratigraphic and geochemical controls on naturally occurring arsenic in groundwater, eastern Wisconsin, USA. *Hydrogeology J.* 2000;8:161–176.

79. *Drinking Water Infrastructure Needs Survey: Second Report to Congress.* Washington, DC: US Environmental Protection Agency; 2001. Report EPA-816-R-01-004.

80. *Clean Water Needs Survey Report to Congress, 1996: Assessment of Needs for Publicly Owned Wastewater Treatment Facilities, Correction of Combined Sewer Overflows and Management of Stormwater and Nonpoint Source Pollution in the United States.* Washington, DC: US Environmental Protection Agency; 1997. Report EPA-832-R-97-003.

81. Hunt WF. Stormwater BMP cost—effectiveness relationships for North Carolina. In: *Proceedings of Watershed 2002: Connecting You to a Higher Level of Expertise.* [CD-ROM] Alexandria, Va: Water Environment Federation; 2002.

82. *The Clean Water and Drinking Water Infrastructure Gap Analysis.* Washington, DC: US Environmental Protection Agency; 2002. Report EPA-816-R-02-020.

83. Schueler TR. Microbes and urban watersheds: concentrations, sources, and pathways. In: Schueler TR, Holland HK, eds. *The Practice of Watershed Protection.* Ellicott City, Md: Center for Watershed Protection; 2000:68–78.

84. *Costs and Benefits of Drinking Water Treatment.* Washington, DC: US Environmental Protection Agency; 1984. Report EPA-600-J-84-371.

85. *An Evaluation: Milwaukee Metropolitan Sewerage District.* Madison, Wis: Legislative Audit Bureau; 2002. Report 02-12.

86. Tufford DL, McKellar HN, Hussey JR. In-stream nonpoint source nutrient prediction with land-use proximity and seasonality. *J Environ Qual.* 1998;27: 100–111.

87. Brabec E, Schulte S, Richards PL. Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. *J Plann Lit.* 2002;16:499–514.

88. *Draft Generic Environmental Impact Statement for the Draft Watershed Regulations for the Protection From Contamination, Degradation and Pollution of the New York City Water Supply and Its Sources.* Corona, NY: New York City Department of Environmental Protection; 1993.

89. Paden C, Shen A. New York City water under pressure. *Inside DEP.* 1995;1(1):1–8.

90. Planning Overlay, 33 Columbus City Codes, ch. 3372, §701–10 (2003).

91. Zheng PQ, Baetz BW. GIS-based analysis of development options from a hydrology perspective. *J Urban Plann Dev.* 1999;125:164–170.

92. Schueler TR. Comparative pollutant removal capability of stormwater treatment practices. In: Schueler TR, Holland HK, eds. *The Practice of Watershed Protection.* Ellicott City, Md: Center for Watershed Protection; 2000:31–36.

93. Yamada K, Funaki T, Honda S, Sugihara M. Study of diffuse source pollution management for land use and drainage system planning. *Water Sci Technol.* 2001;44:203–208.

94. Kronaveter L, Shamir U, Kessler A. Water-sensitive urban planning: modeling on-site infiltration. *J Water Resources Plann Manage.* 2001;127:78–88.

95. Kaufman MM, Wurtz M. Hydraulic and economic benefits of downspout diversion. *J Am Water Resources Assoc.* 1997;33:491–497.

Lay Down at October 15, 2014 HAPC Meeting

Planning Commission
City of Homer
491 East Pioneer Avenue
Homer, AK 99603

October 15, 2014

RE: Bridge Creek Watershed

Dear Honorable Commissioners:

First, I want to thank you for your commonsense approach to the Bridge Creek Watershed issue and the development limitations. I think the provisions outlined in the letter I received dated October 3, 2014, are logically, thoughtful, and balanced between preservation and development.

I am sorry I am not able to attend the meeting tonight, but I have a previous obligation with Hospice of Homer (we are having an open house tonight and would love for you all to stop by!). But I did want to provide an example on how these changes would affect my property, only as a real-life illustration of the impact. I have 1.45 acres, with a foot print of 912 sf plus a 2 stall garage. According to the borough site, my total developed square footage is 6,065, over the new allowable 5500sf. We built prior to the watershed designation and prior to annexation. We have a flat lot with no sloping.

My example is not a plea for a larger allocation for development, simply an example of the impact to existing property owners. I do appreciate the outbuilding provision as well as the decking.

I am not sure you will find this letter useful, but did want to extend my appreciation for your common sense approach.

Sincerely,

Julie Woodworth
1200 Queets Circle
PO Box 1012
Homer, AK 99603

RECEIVED
OCT 15 2014
CITY OF HOMER
PLANNING/ZONING

Lay Down at October 15, 2014 HAPC Meeting

To: Planning Commission (City of Homer)
From: Phil Clay
Lot owner BCWPD

Thank you for addressing the development limitations for the Bridge Creek Water Shed District. I believe the existing rules for development in the area are too restrictive regarding the amount of property that may be developed, especially for the smaller lots.

I purchased 2 lots in the East Highland Sub. before the rules were put in place, with the intent of building a large house for a bed and breakfast. After just a short time the rules went into effect which made it impossible to follow through with our plan. (The lots are not contiguous)

The new proposed rules would be a step in the right direction, but I believe still does not go far enough in allowing property development. If the proposed change includes driveways, this 5500 square foot limitation may still be too restrictive if a long driveway is needed to reach the building site. I would like to see more like a 7500 square foot allowance for development of lots under 3 acres.

Thank you for your time and attention.

Phil Clay

(This is a transcription of the original letter by Travis Brown. Original letter is on reverse.)

10-15-14

TO: Planning Commission (City of Homer)
From: Phil Clay
lot owner BCWSD

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Thank you for your time & attention

Phil Clay

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CITY OF HOMER
PLANNING/ZONING

Cook Inletkeeper
3734 Ben Walters Lane
Homer, Alaska 99603

p. 907.235.4068
f. 907.235.4069
www.inletkeeper.org

October 15, 2014

Don Stead, Chair
Homer Advisory Planning Commission
491 East Pioneer Avenue
Homer, Alaska 99603

Dear Chairman Stead:

Please accept these comments on behalf of Cook Inletkeeper (Inletkeeper) and its more than 500 members and supporters in the Homer area.

I. Background:

As a threshold matter, Inletkeeper recognizes the Bridge Creek Watershed as a vital community asset. Across the nation and the world, there's no more important community resource than clean, accessible and plentiful drinking and domestic water. We need look no further than the current drought conditions in California to understand how important and valuable municipal water supplies are to local families and businesses.

That's why Inletkeeper played an active role in supporting the City of Homer's efforts to obtain jurisdiction over the Bridge Creek Watershed from the Kenai Peninsula Borough, and why we also worked hard with a broad coalition of people and groups to secure the common-sense safeguards found in the current Bridge Creek ordinance.

II. Concerns

a. **Precedent:** The current ordinance is not perfect, but it's been effective to control nonpoint source pollution into the City's drinking water supply. The proposed changes, however, drive a substantial hole in the ordinance, and allow impervious cover up to 12% or more on parcels under 3 acres – more than double what's currently allowed, with no mitigation plan requirement. While the proposed ordinance includes some mitigation requirements, the mitigation plans currently required for impervious cover above 6.4% is missing. These shortcomings create a dangerous precedent that can pave the way for additional rollbacks in years to come. For example, what's to stop the owner of a larger parcel – after seeing changes made for owners of smaller parcels - to request increased impervious cover in the future, or to request a waiver of the mitigation plan requirement? This is an important precedent involving the City's sole drinking water source, and the City needs a strong rationale to open the door to rollbacks.

b. **Need:** Furthermore, these changes have apparently been prompted by concerns from some who feel the current ordinance is having a chilling effect on property sales, development and/or values. Yet the background materials for the proposed ordinance do not include any concrete basis on which to justify the considerable changes envisioned. As a result, the Planning Commission should rest its decision on specific concerns, and if they're valid, craft narrowly-tailored changes – including the opportunity for site-specific variances - to address those concerns.

c. **Other Pollutants:** Next, the prospect of increased development in the Bridge Creek Watershed District also highlights a shortcoming in the current ordinance. Specifically, there are no best management practices or mitigation measures required to address polluted runoff from nutrients/fertilizers and herbicides. If the Planning Commission opts to move ahead with increased development on smaller parcels, it should recognize the likely increase in fertilizers and herbicides which will accompany such increases, and address them.

d. **Overall Mitigation:** Additionally, the proposed ordinance attempts to address nonpoint source pollution through parcel-by-parcel mitigation practices. Yet based on the close proximity of the lots in Kelly Ranch Estates and the natural contour/topography of the subdivision sloping toward the Bridge Creek drainage, roads and driveways will act as conduits for runoff. Therefore, it makes more sense to address mitigation on a subdivision scale. This could be through retention basins, swales and other best management practices that would capture and control all or most of the water from the subdivision.

e. **Impervious Extent:** The proposed ordinance includes an extra 700 sq. ft. for decks and out buildings, yet there's no basis in the record or elsewhere to segregate these structures from the overall impervious coverage calculation. Impervious cover is impervious cover and should be included in the final overall parcel calculation, regardless the source.

III. Conclusion & Recommendations

In closing, I'd like to reiterate the point I made at the Planning Commission's last meeting: the Bridge Creek Reservoir is Homer's only drinking water supply, and it is always – always – cheaper and easier to prevent pollution in a municipal drinking water source then to treat the problem after it occurs. Living within the Bridge Creek Watershed District carries a substantial public obligation, and individuals wishing to develop more extensively on their parcels have a wide range of options outside of the City's sole drinking water source.

As a result, Inletkeeper feels the current proposal goes too far with too little information, and recommends the Planning Commission:

- Quantify the concerns from realtors and/or property owners to understand any diminution in value caused by the current ordinance to parcels under 3 acres in the Bridge Creek Watershed District;

- Develop a subdivision-scale mitigation plan to address the cumulative effects of run-off from Kelly Ranch Estates;

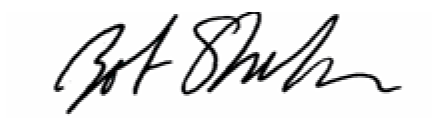
- Re-work the ordinance to include provisions to mitigate the use of fertilizers and herbicides;

- Include decks and outbuildings in the impervious surface coverage calculation for an entire parcel so there's a more accurate assessment of impacts;

- Conduct a study to understand the range of treatment costs City ratepayers would bear in the event turbidity, suspended solids, nutrient or herbicide levels exceed the standards of the Safe Drinking Water Act.

Thank you for your attention to this important matter and feel free to contact me with any questions.

Very truly yours,



Bob Shavelson
Inletkeeper

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10/15/2014

CITY OF HOMER
PLANNING/ZONING

City of Homer
www.cityofhomer-ak.gov

Planning
491 East Pioneer Avenue
Homer, Alaska 99603
Planning@ci.homer.ak.us
(p) 907-235-3106
(f) 907-235-3118

STAFF REPORT PL 14-93

TO: Homer Advisory Planning Commission
THROUGH: Julie Engebretsen, Deputy City Planner
FROM: Dotti Harness-Foster, Planning Technician
MEETING: November 5, 2014
SUBJECT: Request for a Public Sign for Jack Gist Park

Requested Action: Conduct a public hearing and approve a Public Sign for Jack Gist Park.

Applicant: City of Homer Public Works Department
Land owner: Harmon Hall, 64362 Bridger Road, Homer AK 99603
Location: 2161 East End Road, SCENIC VIEW SUB SCENIC GROVE ADDN NO 1 2013 REPLAT LOT 2-A-1

Introduction

The City of Homer is applying for a Public Sign, to place an off premise sign along East End Road, to provide direction to Jack Gist Park. The sign is proposed to be placed on a vacant private parcel, belonging to Mr. Hall. As staff was writing this report, staff found that the preferred location may actually be in Alaska DOT right of way. The City has worked hard to avoid being in the right of way, but with the slope of the land and without a survey it's hard to pinpoint the exact property line. This will need to be done prior to construction.

Staff is requesting Commission approval of the sign and approximate placement; staff will then work with DOT for approval and permitting if in fact it is DOT property. This public sign has been complicated for the City to accomplish: it doesn't make sense to work through any more scenarios and permitting until the City has approval for the sign. Therefore, to move forward with a sign so the public can find the park, we request approval of the sign and approximate location. If there are significant changes in sign location, it will be brought back to the Commission for approval.

Analysis

Homer's Sign Code requires all proposed Public Signs to be reviewed and approved by the Homer Advisory Planning Commission after conducting a public hearing, HCC 21.60.097 Public Signs. The Jack Gist Park sign is a public sign because it provides direction to the Jack Gist Park and is off-premise, per HCC 21.60.040 Definitions:

> **“"Public sign" means an off-premises sign other than an official traffic control device, that provides direction or information, or identifies public facilities such as parks, playgrounds, libraries, or schools or a distinct area of the City, such as Pioneer Avenue, the Homer spit, Old Town and entrances to the City.”**

In 2013 the Public Arts Committee and the Parks and Recreation Commission developed a standardized sign design for all the City's parks. This was supported by the City Council, Resolution 14-024, and the proposed Jack Gist Park sign follows the standards.

The proposed Jack Gist Park sign will be 24 sf with a maximum height of 10 feet (from the crown of the road). Installation is planned for the spring of 2014 and long-term maintenance will be provided by the City.

4 ft

Maximum height of 10 ft. from the crown of the road.

6 ft

Location: The sign will be located on the southeast side of East End Road between Scenic View Drive and Adams Drive. The sign will be approximately 200 feet prior to Adams Drive, giving motorists notice to turn at the next right onto Adams Drive. There are existing 24 inch by 30 inch brown and white reflective signs along East End Road, but they are too small to be effective. The City installed these signs with approval from DOT, and they are not covered by the sign code because they are considered a traffic control device, which is not regulated by the sign code.

Photo details: Eastbound on East End Road. Adams Drive sign. Existing Jack Gist sign.

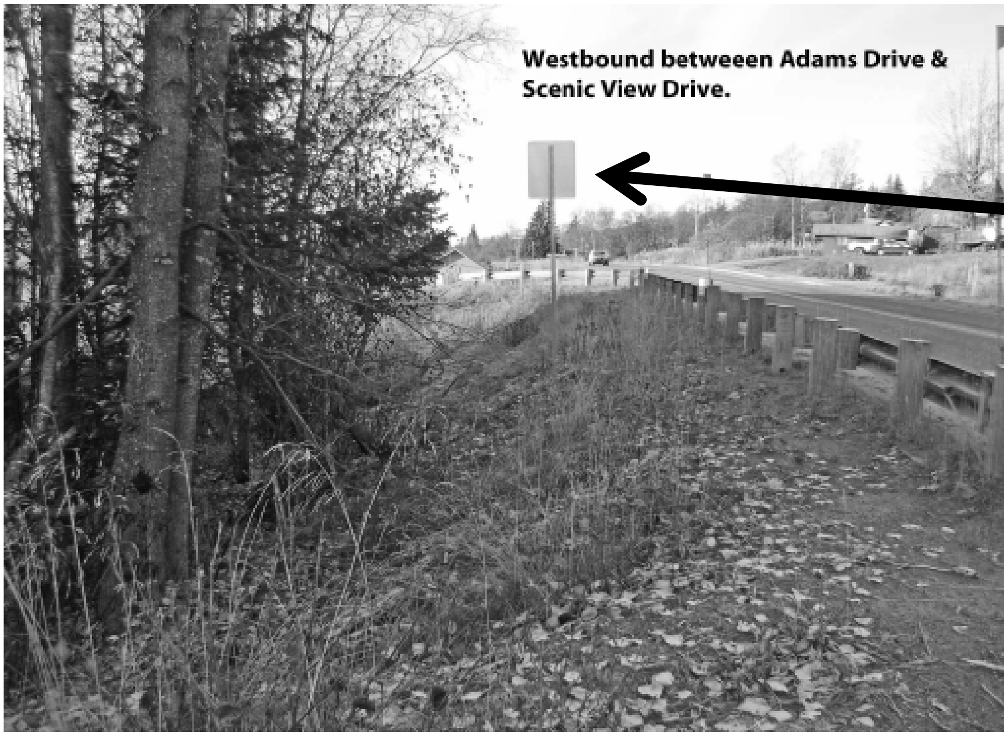

Photo details:

Westbound on East End Road.

Back side of the existing Jack Gist sign.

Sign is approx. 220 feet west of Adams Dr.

HCC 21.60.097 Public Signs. Public Signs are allowed in all zoning districts subject to the requirements in Tables 1, 2 and 3 of HCC § 21.60.060, and to the following requirements:

a. Public Signs are allowed on publicly owned and privately owned lots.

Finding: Public Signs are allowed on public or privately owned lots. The owners of the property have granted permission for placement of the sign on their property. Staff is also seeking approval from State of Alaska, Department of Transportation for placement of a Jack Gist Park sign in the right-of-way.

b. Public Signs are allowed in rights-of-way, subject to HCC § 21.60.090.

Finding: Staff will seek approval from State of Alaska, Department of Transportation for placement of a Jack Gist Park sign in the right-of-way.

c. No more than one Public Sign is allowed per lot.

Finding: There is no other Public Sign on the lot.

d. No Public Sign may be placed within 300 feet of another Public Sign.

Finding: There is no other Public Sign within 300 ft.

e. Freestanding Public Signs shall not exceed 32 square feet in area.

Finding: The proposed sign does not exceed 32 square feet in area. The proposed sign is 24 square feet.

f. Freestanding Public Signs shall not exceed 10 feet in height.

Finding: The proposed sign will not exceed 10 feet in height. The location of the proposed sign slopes downhill away from East End Road. HCC 21.05.030(d) describes "normal grade" based on the elevation of the crow of the road:

> d. When determining the height of a nonbuilding structure, such as a sign or fence, the height shall be calculated as the distance from the base of the structure at normal grade to the top of the highest part of the structure. For this calculation, normal grade shall be construed to be the lower of (1) existing grade prior to construction or (2) the newly established grade after construction, exclusive of any fill, berm, mound, or excavation made for the purpose of locating or supporting the structure. In cases in which the normal grade cannot reasonably be determined, structure height shall be calculated on the assumption that the **elevation of the normal grade at the base of the structure is equal to the elevation of the nearest point of the crown of a public street** or the grade of the land at the principal entrance to the main building on the lot, whichever is lower.

g. Public Signs other than freestanding shall not exceed 24 square feet in area.

Finding: Not applicable because the proposed sign is a freestanding sign.

h. No Public Sign is allowed without a permit.

Finding: A sign permit will be obtained prior to construction.

i. Public Sign design and placement must be submitted to the Planning Commission for approval, including Public Signs provided or installed by the City of Homer.

Finding: The HAPC hereby approves the proposal.

j. The Planning Commission shall conduct a public hearing prior to approving a Public Sign.

Finding: The Planning Commission is conducting a public hearing on November 5, 2014. Based on the Kenai Peninsula Borough tax assessor rolls, 15 property owners owning 16 parcels within 300 feet of the property boundaries received public notice. Public notice was also advertised in the local newspaper.

Staff recommendation: Planning Commission approval of the Jack Gist Park sign with findings.

Attachments

1. Letter from Public Works Director, Carey Meyer
2. Permission from property owner
3. Area photos
4. Public notice
5. Aerial Map

City of Homer

www.cityofhomer-ak.gov

Public Works
3575 Heath Street
Homer, AK 99603
publicworks@cityofhomer-ak.gov
(p) 907- 235-3170
(f) 907-235-3145

October 21, 2014

Dear Homer Advisory Planning Commission:

The City of Homer Public Works Department would like to install a public sign at 2161 East End Road, for Jack Gist Park. A proof of the sign and a map showing the proposed location is attached. This section of East End Road has a speed limit of 45 MPH, so the sign needs to be large enough to read and allow people to slow down and turn right onto what is currently Adams Drive. The park property is approximately 1000 feet down Adams Drive/Jack Gist Lane.

The sign will be located on property belonging to Harmon Hall, at 2161 East End Road, KPB# 17924036, Lot 2-A-1 Scenic View Subdivision Scenic Grove Addn No 1 2013 Replat. He signed letter grating permission is attached.

The sign itself will be 6'x4', with additional area for the city logo (see proof). The sign will be installed to meet the height standards of 21.60.097, which requires the top of the sign not extend higher than 10 feet above the adjacent crown of East End Road.

Applicant Signature: Carey Meyer   Date: 10/21/14

Carey S. Meyer, P.E., MPA
Public Works Director

Attachments:

1. Sign proof
2. Map of proposed location
3. Property owner permission

I grant permission for the City to apply for a sign permit and install a sign for Jack Gist Park on my property located at 2161 East End Road, KPB# 17924036, Lot 2-A-1 Scenic View Subdivision Scenic Grove Addn No 1 2013 Replat.

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CITY OF HOMER
PLANNING/ZONING

Adams Drive, look west toward proposed sign location

Looking east toward Adams Drive. Proposed sign would be placed closer to the driveway approach, shown on the lower portion of the photo.

Adjacent Grade

View from north of East End Road, looking south to the proposed sign location.

PUBLIC HEARING NOTICE

Public notice is hereby given that the City of Homer will hold a public hearing by the Homer Advisory Planning Commission on Wednesday, November 05, 2014 at 6:30 p.m. at Homer City Hall, 491 East Pioneer Avenue, Homer, Alaska, on the following matter:

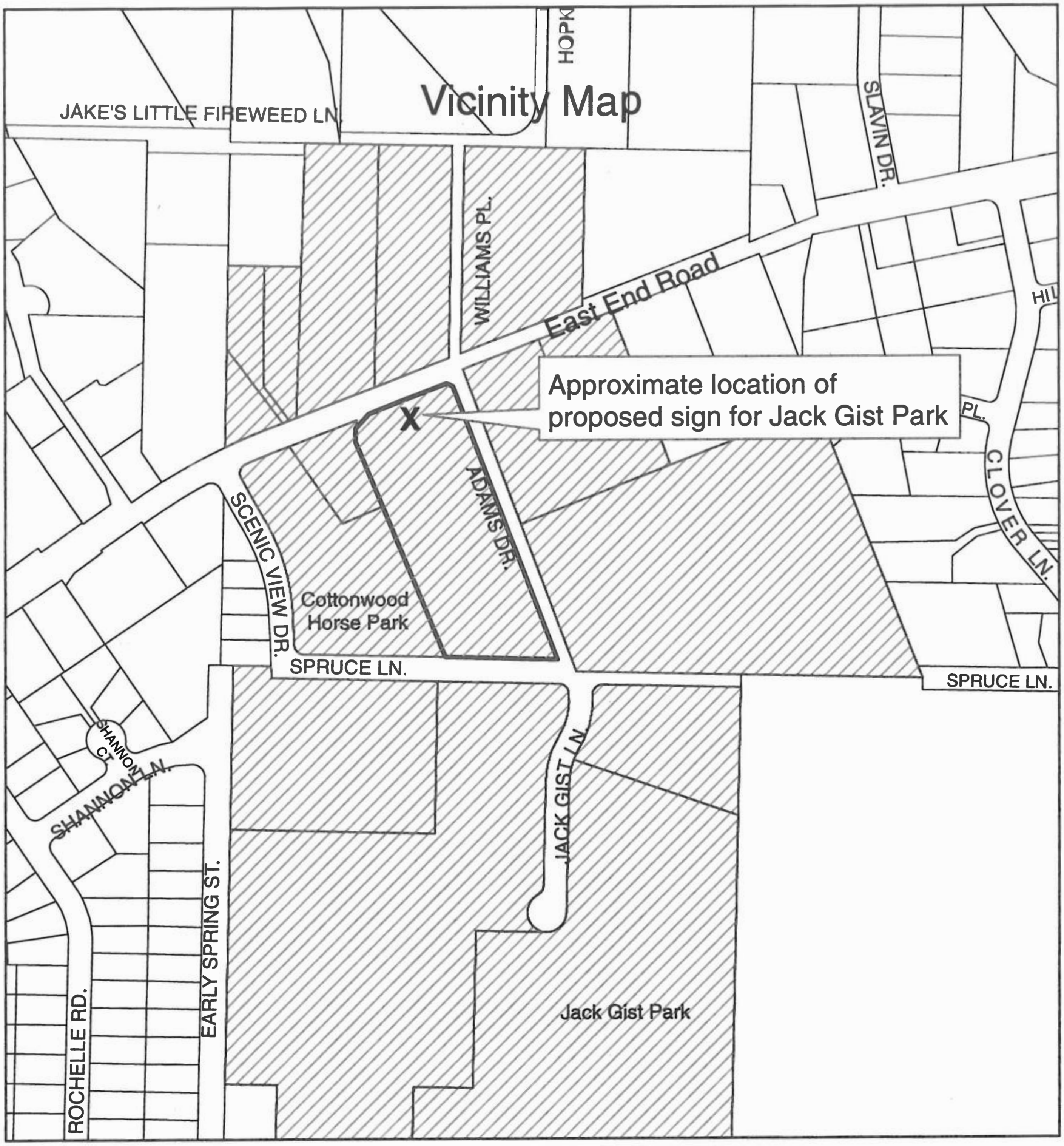
Request to install a public sign for Jack Gist Park at 2161 East End Road, pursuant to HCC 21.60.097(j). Legal description of property is lot 2-A-1 Scenic View Sub. Scenic Grove Addition No. 1 2013 Replat T 6S R 13W SEC 15 S.M.

Anyone wishing to present testimony concerning this matter may do so at the meeting or by submitting a written statement to the Homer Advisory Planning Commission, 491 East Pioneer Avenue, Homer, Alaska 99603, by 4:00 p.m. on the day of the meeting.

The complete proposal is available for review at the City of Homer Planning and Zoning Office located at Homer City Hall. For additional information, please contact Travis Brown at the Planning and Zoning Office, 235-3106.

NOTICE TO BE SENT TO PROPERTY OWNERS WITHIN 300 FEET OF PROPERTY.

VICINITY MAP ON REVERSE



City of Homer

Planning and Zoning Department

10/24/14

Request for a Public Sign

Shaded lots are within 300 feet and property owners notified.

Feet

0 150 300 600

N

Disclaimer:
It is expressly understood the City of Homer, its council, board, departments, employees and agents are not responsible for any errors or omissions contained herein, or deductions, interpretations or conclusions drawn therefrom.

Proposed New Jack Gist Park Sign Location Map

4'

6'

City of Homer
Planning and Zoning Department
10/24/14

Legend

Wetland Drainages

5 Foot Topo

Feet
0 105 210

N

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City of Homer
www.cityofhomer-ak.gov
Office of the City Manager
491 East Pioneer Avenue
Homer, Alaska 99603
citymanager@cityofhomer-ak.gov
(p) 907-235-8121 x2222
(f) 907-235-3148

MANAGER'S REPORT
October 13, 2014

TO: MAYOR WYTHE / HOMER CITY COUNCIL

FROM: WALT WREDE

UPDATES / FOLLOW-UP

NOTE: Some of these items appeared in the last report. I have updated them and brought them back in case the Council wanted to discuss.

1. HERC Building Property / Deed Restrictions: The Borough Assembly will be introducing an ordinance to remove the deed restrictions as requested by the Council at its regular meeting on October 14th. The Borough Administration asked if I could attend the committee meeting and the regular meeting, to answer any questions that might come up. I will plan to do so.
2. PARC Needs Assessment Update: The Needs Assessment project is up and running. It is live. The community survey is open and everyone is encouraged to participate. Results from the community survey's completed in October will be used to shape the community meeting in November. The survey will run until December 1st, but people are encouraged to participate early. The community meeting will be Thursday, November 13th, in the evening at Islands and Ocean Visitor Center. You can find the survey and more information on the City of Homer website under Parks and Recreation. Attached is a flyer that will be in Thursday's newspaper. The PARC Committee strategy for getting the word out includes:

- 3000 newspaper inserts
- Newspaper article in Homer News this week
- Advertising and article in next week's Tribune.
- Radio advertising
- Mass e-mails inviting people to participate in the survey

This is a general survey for all residents. In a later phase, provider surveys will be sent out to parks and recreation providers that are more specific to them and their services.

The link to the survey is http://www.cityofhomer-ak.gov/recreation/park-art-recreation-and-culture-needs-assessment-parc

3. Jeff Paxton / Mercer: The Council has become familiar with Jeff Paxton because he has submitted reports and made presentations to it regarding employee health insurance. Jeff has played a crucial role in helping us get the City's health insurance costs under control and is assisting us with adapting to the requirements of the ACA. Some have commented to the Council that the City pays Mercer too much for what it receives in services. Some have asked if the City still needs Mercer if it chooses to drop self- insurance and go with a private insurance firm. It has occurred to me that the Council may not have a full and complete picture of the range of services Jeff is providing under the contract. I have probably been doing him a disservice myself by consistently referring to him as our insurance broker. I think this might leave people with the impression that all he does is solicit bids for insurance services. In reality, he does much more than that. He is really a benefits consultant and he assists HR on a full range of benefits from life insurance to flexible spending accounts. In some ways, it is appropriate to think of Mercer as an extension of the HR department responsible for benefits. In a way, we are outsources this HR function. Attached is a copy of the scope of work included in Mercer's current contract. Also attached is a copy of Mercer's on-line newsletter. I hope this will provide you with a better understanding of Mercer's value and how we use them.
4. Budget Memorandums: We are now officially in the budget season. A draft of the budget will be provided to the Council at the Committee of the Whole on October 13th. The budget is scheduled to be introduced by ordinance on October 27.Attached are two budget related memorandums for your information and discussion. One memorandum describes how labor costs were reallocated between the Public Works General Fund Budget and the Water and Sewer Special Revenue Fund Budget. The other addresses Employee Health Care. A broader budget message will be distributed along with the draft budget on the 13th.

ATTACHMENTS

1. Library Director's Report
2. PARC Needs Assessment Flyer
3. Jeff Paxton / Scope of Work
4. Memorandum 14-156 from Public Works Director, Re: Labor Cost Reallocation / PW and Water and Sewer
5. Capital Project Status Report
6. Memorandum 14-158 from Community & Economic Development Coordinator, Re: Updated Comp Plan Implementation Schedules
7. Memorandum 14-159 from City Manager, Re: Special Budget Report on Employee Health Insurance
8. Letter from Alaska Board of Fisheries

City of Homer
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Homer, Alaska 99603
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(f) 907-235-3148

MANAGER'S REPORT
October 27, 2014

TO: MAYOR WYTHE / HOMER CITY COUNCIL

FROM: WALT WREDE

UPDATES / FOLLOW-UP

NOTE: Some of these items appeared in the last report. I have updated them and brought them back in case the Council wanted to discuss.

1. MAPP Request for Support: Mobilizing for Action through Planning and Partnerships (MAPP) is applying for a $200,000 Federal HRSA grant to support their work on family issues in Homer. The City Council passed Resolution 12-085 in 2012 in support of the previous HRSA grant application which was funded and was used for strategic planning. MAPP has requested a resolution of support for this grant application as well. Unfortunately, a communication malfunction prevented a resolution from making it on this agenda and the application deadline will have passed by the next time the Council meets on November 24. Therefore, I will go ahead and write a letter of support on behalf of the Council and the City, unless there are objections from Council members.
2. PARC Needs Assessment Update: At the last meeting, Matt Steffy, the PARC Chair fielded some questions regarding the PARC initial needs assessment survey. After the meeting, I realized that the Council had not been briefed on the full assessment strategy and the thinking behind it. I asked Julie to write a memo summarizing the research methodology for the Council. That memorandum is attached. I have scheduled a PARC visitor presentation for the meeting on November 24. The purpose of that presentation is to provide an update on how the Needs Assessment is progressing so far. Updates on the community meetings will be included. Also, several Council members have asked recently how arts and culture got added into this assessment when the original intent of the Council was parks and recreation. This was explained to the Council at a presentation early on by Matt Steffy but you may not recall. This issue can also be addressed non November 24. I understand that a PARC representative may also be present at this meeting to make some comments on this topic.
3. Harbor Electric Upgrades: As some of you may be aware, the electrical upgrades installed in the harbor had some unintended consequences and the harbor staff have been scrambling to find a solution. Attached is a memorandum from the Deputy harbormaster

to vessel owners explaining that the state has granted a temporary grace period for implementing GFI protection and the requirements of the electrical code.

4. Budget Memorandums: The budget is scheduled to be introduced by ordinance at this meeting, October 27.Resolutions on the fee schedule and the Port and Harbor tariff are attached to it. A budget briefing and discussion is scheduled for both the 4 PM Special Meeting and the 5 PM Committee of the Whole. After the ordinance is introduced, it becomes the Council's budget and can be amended as Council deems appropriate. As always, we should have more current revenue information later in November.
5. Benefits Consultant RFP: This agenda contains a resolution sponsored by Council Member Burgess which calls for an RFP for benefits consultant services. In most circumstances, I would be totally in agreement with this. Our current contract with Mercer has been for three years. Seeking proposals would be a good idea if we thought we needed these services again in 2015. However, if the Council agrees to move to a fully insured private plan, we may not need a consultant at all. And if we do need one, it would be for a significantly reduced fee and scope of work. This is what we recommend. Given that the contract would be smaller, we have an already established relationship with Mercer, Mercer is familiar with the City, its benefits, and its employees, and we could use help with the transition, we recommend a smaller contract, for six months or a year, and that we stay with Mercer. In my view, they have provided excellent service.
6. Natural Gas: We are working with Enstar to finalize the total construction cost, checking the preliminary assessment roll, and other activities. Council can expect a report on the Natural Gas Special Assessment District at the next meeting on November 24.
7. AML / AMMA: I will be attending the AML and Alaska Municipal Managers meetings in Anchorage the week of November 17. I do not require a vehicle or lodging while in Anchorage. I will pay the registration fees myself since I am soon leaving City service. I think there is still value to the City in having me attend.

ATTACHMENTS

1. Memorandum 14-170, re: PARC Needs Assessment Strategy
2. Communication to vessel owners re: GFI protection

KENAI PENINSULA BOROUGH

PLANNING DEPARTMENT
144 North Binkley Street • Soldotna, Alaska 99669-7520
PHONE: *(907) 714-2200* • ***FAX:*** *(907) 714-2378*
Toll-free within the Borough: 1-800-478-4441, Ext. 2200
www.borough.kenai.ak.us

MIKE NAVARRE
BOROUGH MAYOR

October 20, 2014

NOTICE OF DECISION
KENAI PENINSULA BOROUGH PLAT COMMITTEE

MEETING OF OCTOBER 13, 2014

RE: Homer Enterprises, Inc. Subdivision Resetarits Replat Preliminary Plat

The Plat Committee reviewed and granted conditional approval of the subject preliminary plat during their regularly scheduled meeting of October 13, 2014 based on the findings that the preliminary plat meets the requirements of the Kenai Peninsula Borough Code 20.25; 20.30; and 20.40.

This notice and unapproved minutes of the subject portion of the meeting were sent October 20, 2014 to:

City of: City of Homer
491 East Pioneer Avenue
Homer, AK 99603

Advisory Planning Commission/Community Council: Homer Advisory Planning Commission
491 East Pioneer Avenue
Homer, AK 99603

Survey Firm: Segesser Surveys
30485 Rosland St.
Soldotna, AK 99669

Subdivider/Petitioner: Anthony Resetarits
Joseph Resetarits
PO Box 3063
Homer, AK 99603-3063

KPB File Number: 2014-139

AGENDA ITEM E. SUBDIVISION PLAT PUBLIC HEARINGS

Staff Report given by Paul Voeller   Plat Committee Meeting: 10/13/14

Staff has grouped the plats located under ***AGENDA ITEM E (AGENDA ITEM F - FINAL PLATS WILL NEED SEPARATE REVIEW).*** They are grouped as:

A. ***Simple*** (lot splits, small number of lots, replats, no exceptions required) or non-controversial (may require redesigns, create larger number of lots, no public comments received, no exceptions required) – 5 Plats

1. Creekside Heights No. 4; KPB File 2014-134 [Johnson / Tornai]
2. VIP Country Estates Sub Part 5 2014 Replat; KPB File 2014-137 [Johnson / Penner]
3. Correia Sub 2014 Addition; KPB File 2014-138 [Johnson / Mattox]
4. Whispering Meadows Sub Rich Replat; KPB File 2014-135 [McLane / Rich]
6. Homer Enterprises Inc. Sub Resetarits Replat; KPB File 2014-139 [Segesser / Resetarits]

Staff recommends the committee determine whether any members of the public, surveyors or committee members wish to speak to any of the plats in this group and remove the specific plats from the group, voting on the remainder of plats in the group in a single action to grant preliminary approval to the plats subject to staff recommendations and the conditions noted in the individual staff reports.

END OF STAFF REPORT

Chairman Ruffner opened the meeting for public comment. Seeing and hearing no one wishing to comment, Chairman Ruffner closed the public hearing and opened discussion among the Committee.

MOTION: Commissioner Martin moved, seconded by Commissioner Isham to grant approval of the following preliminary plats as presented by staff.

1. Creekside Heights No. 4; KPB File 2014-134 [Johnson / Tornai]
2. VIP Country Estates Sub Part 5 2014 Replat; KPB File 2014-137 [Johnson / Penner]
3. Correia Sub 2014 Addition; KPB File 2014-138 [Johnson / Mattox]
4. Whispering Meadows Sub Rich Replat; KPB File 2014-135 [McLane / Rich]
6. **Homer Enterprises Inc. Sub Resetarits Replat; KPB File 2014-139 [Segesser / Resetarits]**

VOTE: The motion passed by unanimous consent

CARLUCCIO ABSENT	COLLINS YES	HOLSTEN ABSENT	ISHAM YES	MARTIN YES	RUFFNER YES	WHITNEY YES	5 YES 2 ABSENT

AGENDA ITEM E. SUBDIVISION PLAT PUBLIC HEARINGS

6. Homer Enterprises Inc. Subdivision Resetarits Replat
KPB File 2014-139; Segesser/Resetarits

STAFF REPORT   Plat Committee Meeting: 10/13/14

Location: City of Homer
Proposed Use: Residential
Water/Sewer: City
Zoning: Urban Residential
Assessing Use: Vacant
Parent Parcel Number(s): 175-111-09, 175-111-10

Supporting Information:

The proposed subdivision is a simple replat of two lots into one lot containing 13,525 square feet. The subdivision is served by city water and sewer. The plat fronts constructed West Fairview Avenue.

Homer Advisory Planning Commission approved the plat on September 3, 2014 subject to:

1. Change Plat Note #3: The front 15 feet along the right-of-way is a utility easement. No permanent structure shall be constructed or placed within the utility easement which would interfere with the ability of a utility to use the easement.

   Note: staff (Homer City planning staff) does not recommend stating building setbacks in plat notes; see recommendation #4. Additionally, city code does not require 5 foot side utility easements.
   Borough Staff Comments: The first two plat notes are on the plat submitted for KPB review. ***Staff recommends*** *the 20-foot building setback note be removed from the plat. Building setbacks are set by the city's zoning district per KPB 20.30.250. Utility reviews were not available when the staff report was prepared. The other utility providers may request a utility easement on the side lot lines.*

2. Delete Plat Note 4.
   Borough Staff Comments: Plat Note 4 was deleted from the plat submitted for KPB review. The surveyor was correct; KPB Code requires this note. ***Staff recommends*** *the plat note per KPB 20.40.070 be placed on the final plat.*

3. Add plat note: This lot is served by City water and sewer.
   Borough Staff Comments: The requested note is on the plat submitted for KPB review.

4. Add plat note: Development activity subject to City of Homer zoning regulation.
   Borough Staff Comments: The requested note is on the plat submitted for KPB review.

5. Depict the 15-foot utility easement on the plat.
   Borough Staff Comments: The requested easement is on the plat submitted for KPB review.

6. Depict the approximate location of the City's wastewater and water mains on the plat.
   Borough Staff Comments: City water and sewer lines have been shown and labeled on the plat submitted for KPB review.

7. Label the proposed lot size on the lot.
   Borough Staff Comments: The requested information was provided on the plat submitted for KPB review.

8. Label the lot line to be removed.
   Borough Staff Comments: The former lot line has been shown and labeled on the plat submitted for KPB review.

9. Adjust scale of the vicinity map so the location of the proposed subdivision is more easily identified.
   Borough Staff Comments: The plat submitted for KPB review has a detail view of the proposed plat in the vicinity map.

Per the preliminary Certificate to Plat, beneficial interest holders do not affect the proposed plat. Notification per KPB 20.25.090 will not be required unless the final Certificate to Plat states the property is affected by beneficial interest holders.

Physical addresses may be affected by the replat. Homer Planning and Zoning Department can answer questions about the effect of the replat on addresses.

STAFF RECOMMENDATION: Grant approval of the preliminary plat subject to any above recommendations, and the following conditions and findings:

REVISE OR ADD TO THE PRELIMINARY PLAT IN ACCORDANCE WITH THE PROVISIONS CONTAINED IN KPB 20.25.070 (FORM AND CONTENTS), KPB 20.25.080 (PETITION REQUIRED), KPB 20.30 (DESIGN REQUIREMENTS); AND KPB 20.40 (WASTEWATER DISPOSAL), AS FOLLOWS:

20.25.070 - Form and contents required.

Platting staff comments: The plat complies with the following portions of 20.25.070: B-G, J, and K.

Platting staff comments: The following portions of 20.25.070 are not applicable to the subject plat: I, L, N and O.

Platting staff comments: Additional information is provided for the following portions of 20.25.070 or additional information, revision or corrections are required

A. Within the Title Block
   1. Name of the subdivision which shall not be the same as an existing city, town, tract, or subdivision of land in the borough, of which a plat has been previously recorded, or so nearly the same as to mislead the public or cause confusion;
   2. Legal description, location, date, and total area in acres of the proposed subdivision; and
   3. Name and address of owner(s), as shown on the KPB records and the certificate to plat, and registered land surveyor;

   Platting Staff Comments: ***Staff recommends*** *the aliquot description be corrected.*

H. Approximate locations of areas subject to inundation, flooding, or storm water overflow, the line of ordinary high water, wetlands when adjacent to lakes or non-tidal streams, and the appropriate study which identifies a floodplain, if applicable;
   Platting Staff Comments: Per KPB GIS mapping, the plat is not affected by low wet areas.

M. Approximate locations of slopes over 20 percent in grade and if contours are shown, the areas of the contours that exceed 20 percent grade shall be clearly labeled as such;
   Platting Staff Comments: Per the Homer City staff report, the plat is not affected by slopes greater than 20 percent. KPB GIS 4-foot contours support this.

20.25.080. Petition required. A petition shall be submitted with each subdivision, abbreviated subdivision and plat waiver subdivision and shall include:

Platting staff comments: The submittal complies with 20.25.080 (A, B, D, and E).

Platting staff comments: The following portion of 20.25.080 is not applicable to the subject plat: C

KPB 20.30 Design Requirements

Platting staff comments: The plat complies with the following portions of 20.30: 20.30.050, 20.30.120, 20.30.170, 20.30.190, 20.30.200, 20.30.210, and 20.30.220.

Platting staff comments: The following portions of 20.30 are not applicable to the subject plat: 20.30.020, 20.30.040, 20.30.090, 20.30.100, 20.30.110, 20.30.130, 20.30.140, 20.30.150, 20.30.160, 20.30.230, and 20.30.260.

Platting staff comments: Additional information is provided for the following portions of 20.30 or additional information, revision or corrections are required

20.30.030. Proposed street layout-Requirements.

Platting Staff Comments: Notice of the proposed subdivision was mailed to DOT as part of the routine agency notification process. The plat does not front a State right-of-way.

20.30.060. Easements-Requirements.
Platting Staff Comments: The affected utility providers were mailed the subdivision plat public hearing notice as part of the routine notification process. ***Staff recommends*** *compliance with 20.30.060.*

20.30.070. Lots on major streets-Access requirements.
Platting Staff Comments: KPB Roads Department submitted a statement of no comments. The plat does not front a KPB right-of-way.

20.30.080. Alleys. Alleys are prohibited unless allowed by city ordinance.
Platting Staff Comments: Homer Advisory Planning Commission did not recommend alleys.

20. 30.180. Pedestrian ways required when.
Pedestrian ways not less than 8 feet wide shall be required in blocks longer than 600 feet where reasonably deemed necessary to provide circulation or access to schools, playgrounds, shopping centers, transportation or other community facilities.
Platting Staff Comments: Homer Advisory Planning Commission did not recommend pedestrian ways.

20.30.240. Building setbacks.
Platting Staff Comments: Buildings setbacks are not depicted on plats in city limits.

20.30.250. Building setbacks-Within cities.
The building setback requirements for subdivisions located within cities shall be governed by the provisions of municipal zoning districts.
Platting Staff Comments: When the building setback note and depiction are removed, the plat will come into compliance with 20.30.250.

20.30.270. Different standards in cities.
Platting Staff Comments: Homer Advisory Planning Commission did not recommend application of different standards.

20.30.280. Floodplain requirements.
Platting Staff Comments: The City of Homer administers the floodplain program through HCC 21.41 Flood Prone Areas. Per the Homer City staff report, the plat is within Zone D, flood hazards undetermined.

20.30.290. Anadromous habitat protection district.
Platting Staff Comments: Per River Center review, the plat is not affected by the Anadromous Habitat Protection District.

Per KPB GIS mapping, no anadromous streams flow through the subdivision.

KPB 20.40 -- Wastewater Disposal
Platting Staff Comments: ***Staff recommends*** *the wastewater disposal note per KPB 20.40.070 be placed on the final plat.*

ADDITIONAL REQUIREMENTS FOR ADMINISTRATIVE APPROVAL OF THE FINAL PLAT (KPB 20.60)

Platting staff comments: The plat complies with the following portions of 20.60: 20.60.130 and 20.60.140.

Platting staff comments: The following portions of 20.60 are not applicable to the subject plat: 20.60.040, 20.60.050, 20.60.060, 20.60.090, and 20.60.100.

Platting staff comments: Additional information is provided for the following portions of 20.60 or additional information, revision or corrections are required

20.60.010. Preparation requirements generally.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.010.*

20.60.020. Filing-Form and number of copies required.
Platting Staff Comments: ***Staff recommends*** *two full-sized paper copies of the plat be submitted for final review prior to submittal of the Mylar.* ***Staff recommends*** *compliance with 20.60.020.*

20.60.030. Certificate of borough finance department required.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.030.*

20.60.070. Plat specifications.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.070.*

20.60.080. Improvements-Installation agreement required.
A final plat of a subdivision located within city limits shall not be recorded with the district recorder prior to compliance with any city ordinances concerning the installation of improvements. Evidence of compliance shall be provided by the subdivider in the form of a written statement from the appropriate city official that improvements required by city ordinance are or will be installed. Evidence of compliance shall be a part of the final plat submission and the time for action required by KPB 20.60.210 shall not commence until evidence of compliance is submitted.
Platting Staff Comments: Per Homer City Staff Report PL 14-82, an installation agreement is not required.

20.60.110. Dimensional data required.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.110.*

20.60.120. Accuracy of measurements.
All boundary closures shall be to a minimum accuracy of 1:5,000. Boundary and lot closure computations must be submitted with the final plat.
Platting Staff Comments: KPB GIS will verify closure complies with 20.60.120. ***Staff recommends*** *compliance with 20.60.120.*

20.60.150. Utility easements.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.150.*

20.60.160. Easements.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.160.*

Staff recommends *a plat note be provided for the general easement of record granted to Homer Electric Association.*

20.60.170. Other data required by law.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.170.*

Staff recommends *a plat note be provided for the private restrictive covenants including the recording information.*

The borough will not enforce private covenants, easements, or deed restrictions per KPB 21.44.080.

20.60.180. Plat notes.
Platting Staff Comments: Additional plat notes may be required based on easements/covenants in the final Certificate to Plat.

20.60.190. Certificates, statements, and signatures required.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.190.*

Staff recommends *the Certificate of Ownership and Dedication be revised to reflect multiple owners (I to we, am to are, owner to owners, etc.).*

20.60.200. Survey and monumentation.
Platting Staff Comments: ***Staff recommends*** *compliance with 20.60.200.*

Staff recommends *all record monuments be shown unless monuments have been removed for this replat.* ***Staff recommends*** *the surveyor advise staff which monuments have been removed for this replat by mail or email.*

20.60.210. Approval-Authority-Certificate issued when.
Platting Staff Comments: If the Plat Committee conditionally approves the preliminary plat, staff recommends compliance with 20.60.210.

20.60.220. Administrative approval.
Platting Staff Comments: *If the Plat Committee conditionally approves the preliminary plat and the final plat conforms to the conditions, staff will issue an administrative approval with notice to the Planning Commission as set forth in 20.60.220.*

The planning director may refer the final plat to the planning commission when:

1. *Major redesign was a condition of preliminary approval by the planning commission or the advisory planning commission of the city in which the subdivision is located;*
2. *Final approval by the commission was a condition of preliminary approval; or*
3 *The planning director determines there are other conditions to support referral to the commission.*

KPB 20.70 – Vacation Requirements
Platting Staff comments: 20.70 is not applicable to the proposed plat.

NOTE: REVIEW OF A DECISION OF THE PLAT COMMITTEE MAY BE HEARD BY THE PLANNING COMMISSION ACTING AS PLATTING BOARD BY FILING WRITTEN NOTICE THEREOF WITH THE BOROUGH PLANNING DIRECTOR ON A FORM PROVIDED BY THE BOROUGH PLANNING DEPARTMENT. THE REQUEST FOR REVIEW SHALL BE FILED WITHIN 10 DAYS AFTER NOTIFICATION OF THE DECISION OF THE PLAT COMMITTEE BY PERSONAL SERVICE OR SERVICE BY MAIL.

A REQUEST FOR REVIEW MAY BE FILED BY ANY PERSON OR AGENCY THAT PARTICIPATED AT THE PLAT COMMITTEE HEARING EITHER BY WRITTEN OR ORAL PRESENTATION. THE REQUEST MUST HAVE AN ORIGINAL SIGNATURE; FILING ELECTRONICALLY OR BY FACSIMILE IS PROHIBITED. THE REQUEST FOR REVIEW MUST BRIEFLY STATE THE REASON FOR THE REVIEW REQUEST AND APPLICABLE PROVISIONS OF BOROUGH CODE OR OTHER LAW UPON WHICH THE REQUEST FOR REVIEW IS BASED.

NOTICE OF THE REVIEW HEARING WILL BE ISSUED BY STAFF TO THE ORIGINAL RECIPIENTS OF THE PLAT COMMITTEE PUBLIC HEARING NOTICE. CASES REVIEWED SHALL BE HEARD DE NOVO BY THE PLANNING COMMISSION ACTING AS THE PLATTING BOARD (KPB 2.40.080).

END OF STAFF REPORT

B. ***Plats needing specific actions or controversial*** - (public comments received, major staff concerns, exceptions required) – 3 Plats

AGENDA ITEM E. SUBDIVISION PLAT PUBLIC HEARINGS

5. Box Canyon Subdivision Seavey Addn. No. 4