Mapping Impervious Cover to Correlate Land Use Activities with Salmon Health & Habitat on the Lower Kenai Peninsula

FINAL REPORT

PREPARED BY
SUE MAUGER
Cook Inletkeeper

FOR
U.S. FISH AND WILDLIFE SERVICE
GRANT AGREEMENT #70191-5-G344

DECEMBER 2006

COOK INLETKEEPER®
PROTECTING ALASKA'S COOK INLET WATERSHED AND THE LIFE IT SUSTAINS

TABLE OF CONTENTS

Introduction	1
Study Area	2
Impervious Cover Extraction Method	3
Impervious Cover Results	6
Correlation Methods	7
Correlation Results	7
Discussion and Recommendations	8
References	11
Acknowledgements	11
APPENDIX I: Impervious Cover Maps	12

Mapping Impervious Cover to Correlate Land Use Activities with Salmon Health & Habitat on the Lower Kenai Peninsula

Introduction

National studies show that impervious surfaces are indicators of the quality of water resources as they measure the impacts of land development on aquatic systems. In many regions of the country, as little as 10% watershed impervious cover has been linked to stream degradation, with the degradation becoming more severe as impervious cover increases (Schueler, 1995). A more recent urbanization study, however, found effects from impervious cover at much lower levels. For example, a study conducted by USGS in five watersheds in Anchorage, Alaska found threshold responses at 4.4 –5.8% impervious area (Ourso and Frenzel, 2003).

As the amount of impervious surface cover in a landscape increases, a chain of events is initiated that begins with changes to the way that water is transported and stored and results in changes to the hydrologic cycle (Arnold and Gibbons, 1996). Once this chain of events is triggered, the effects are far-reaching, and can result in degraded fish and wildlife habitat, decreased water quality, and impacts to nearshore and marine habitat.

Since 1998, Cook Inletkeeper, in partnership with the Homer Soil and Water Conservation District, has collected water quality, macroinvertebrate and flow data on salmon streams on the lower Kenai Peninsula to better understand watershed health. This ongoing monitoring project has revealed that summer temperatures consistently exceed Alaska's standards and may pose risks to these important salmon streams. Water temperature is one of the most significant factors in the health of stream ecosystems. Temperature affects salmon egg and fry incubation, fish metabolism, resistance to disease, and availability of oxygen and nutrients. Researchers have determined that cold-water fish species may cease to migrate or die un-spawned if exposed to long periods of warmer than usual temperatures (Bell, 1973).

With impervious land cover emerging as an important environmental indicator, it is timely to conduct a comprehensive analysis of impervious surface cover on the lower Kenai Peninsula salmon streams to detect relative effects of land use activities on water quality, water quantity, and fish habitat. The results of this analysis provide important baseline information and will prove useful for natural resource planning, habitat and water quality monitoring, and for effectively addressing a host of complex environmental issues, particularly those related to the health of water resources. Specifically, this project entails synthesizing impervious cover data for the specified watersheds and sub-watersheds into the existing baseline data set. This data set is then used in conjunction with water quality and macroinvertebrate data, to analyze data differences between developed vs. undeveloped portions of the designated watersheds and sub-basins. This analysis, in turn, helps us understand whether in-stream habitat changes are the product of land use activities, climate change, or a combination of the two. Importantly, comprehensive data on impervious surface cover will be useful for the long-term monitoring and management of these valuable public trust resources.

Study Area

The Ninilchik River, Deep Creek, Stariski Creek, and Anchor River watersheds (Figure 1) support important public resources, including renowned recreational and commercial anadromous fish populations of chinook, coho, and pink salmon; Dolly Varden, and steelhead. Little is known about the extent to which migratory birds depend on these watersheds for nesting, staging, and migration. However, thousands of migrating waterfowl and hundreds of thousands of shorebirds depend on the region during their spring migrations. Documented migratory birds in these watersheds include goldeneye, merganzers, spotted and least sandpipers, greater and lesser yellowlegs, belted kingfisher, and whimbrel. Stream habitat in these coastal watersheds also supports a variety of mammals, including muskrat, beaver, and river otter, and the region supports populations of moose, black and brown bears, mink, and coyote. At least one endangered species – the Steller's Eider – is known to frequent the watersheds identified in this project. Finally, each of these watersheds contains an impressive array of wetland types which serve as the biological engines for these rich and productive coastal ecosystems.

These river systems play an integral role in local recreation, culture and economies. At the same time, these waterbodies are located in some of the most densely populated and fastest growing regions in Alaska. As a result, land use activities – including gravel mining, logging, road building and residential development – increasingly threaten salmon stream productivity. In addition, a Spruce Bark beetle infestation has already devastated over one million acres of white spruce forests, contributing significantly to a dramatic shift from a predominantly forested landscape to a more grassland-dominated ecosystem.

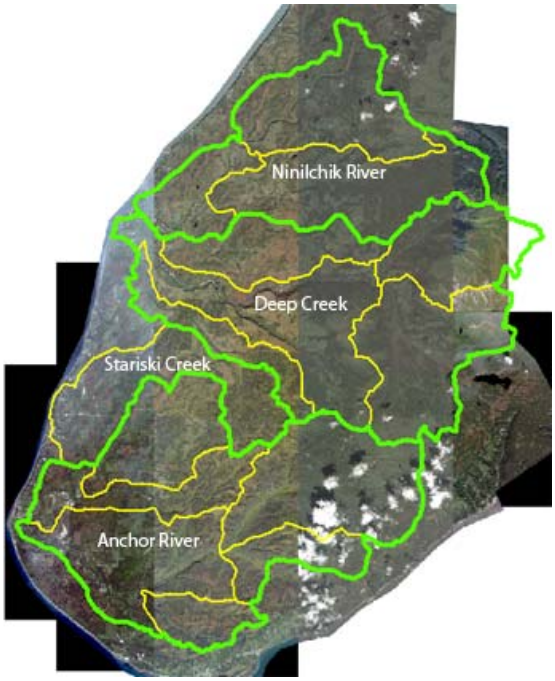


Figure 1. Study area with watershed and sub-watershed boundaries drawn.

Impervious Cover Extraction Method

Cook Inletkeeper project staff met with GIS mapping specialists from the Alaska Center for the Environment and Alaska Pacific University to strategize on how to proceed with impervious surface analysis for this project. Impervious surface analysis methods are evolving and improving quickly. Cook Inletkeeper posted an inquiry on several GIS listservs for feedback on best impervious surface analysis methods, and received nearly 30 responses to this inquiry.

Based on this information and a thorough literature review, Inletkeeper staff decided to pursue a method using Feature Analyst, an ArcGIS extension made by Visual Learning Systems. With this software, the user first digitizes a number of sample impervious surface polygons on an aerial photograph. Feature Analyst then digitizes impervious surfaces in the rest of the layer based on the input examples, creating a polygon layer. The accuracy of the program depends on the accuracy of the user in digitizing the sample polygons and the quality of aerial photography.

Cook Inletkeeper contracted the Kenai Watershed Forum to perform the GIS work. The Kenai Watershed Forum has the Feature Analyst software, trained staff, as well as high quality aerial photography from 2002-2003. The analysis was conducted on a dual 2.40Ghz Xeon chip Dell Precision 650 dual 19" monitor desktop computer. The impervious surface was extracted using Feature Analyst 4.1, an image processing extension that runs on ArcInfo 9.1. The satellite imagery used was 2 foot pixel panchromatic-sharpened Digitalglobe Quickbird imagery (R,G, B bands) collected in the summers of 2002 and 2003.

The original scope of work was to split the impervious surface into several categories of paved and unpaved surfaces including roads, buildings, parking lots, gravel pits, etc. After closer examination of the imagery and consultation with Visual Learning Systems, the company that makes Feature Analyst, it was apparent that there was no way to distinguish between paved and unpaved surfaces with the existing tools and imagery. The best method to extract impervious surfaces was to train, or select sample features representative of the entire surface to be extracted, on all anthropogenic surfaces. The result was one layer which contains impervious and some semi-permeable surfaces, such as gravel pits and exposed soil. The percentage of area that this layer covered in each USGS HUC 6th level watershed within Deep Creek, Ninilchik River, Stariski Creek, and Anchor River drainages was then calculated.

The first step in impervious surface extraction was to create imagery that was manageable to work with. The file size had to be small enough not to freeze the computer but large enough to be an efficient use of time. The images also needed to be broken into smaller sections to account for the differences in display quality from imagery collected in different swaths (Figure 2). The initial image that contained the entire study area was a compressed MrSID (Multi-Resolution Seamless Image Database) image 1.1 Gb in size. It had to be broken into 17 image files, which were decompressed from the process of clipping, outlining just the watershed boundaries.

Training sets that were representative of impervious surfaces were created for each image (Figure 3). The processing then had to be run for each image. Many different settings were used when trying to create multiple classifications, but one setting worked best for combining all layers when separating them proved unsuccessful. The classification settings most commonly used in the "Set Up Learning" function within Feature Analyst were as follows: Land Cover Feature, image resolution of 0.5 meters, resample factor of 2, Manhattan Input Representation with a pattern width of 3, General purpose Learning Algorithm, Aggregate Areas less than 25 pixels, and output a vector format. The image was processed to extract the entire surface and, when necessary, was run through several clean up steps contained within Feature Analyst. Many times manual clean up was needed since the minimum mapping unit of $100ft^2$ picked up quite a bit of noise (shadow, color variations in wetlands, etc.). When the final layers were created for each image, they were fused together to create a comprehensive impervious surface.

Figure 2. Varying display quality of images collected on different dates.

Figure 3. Sample training set.

Many of the surfaces that were obscured by vegetation or shade were not picked up in the extraction (Figure 4a,b). As a result the roads dataset was aligned to fit the centerline of the road network visible on the Quickbird imagery, buffered and merged with the extracted layer to fill in the gaps (Figure 4c). While there are many roads datasets of the area we were unable to attain one that fit the roads as well as was needed for this step. The widths of major and logging roads were buffered by 30 feet and driveways and smaller roads were buffered by 20 feet. By integrating the road buffer 25% more anthropogenic surface was picked up.

Another reason this step was imperative was that select areas could not be processed to pull out impervious surfaces because they were obscured by cloud cover. In these instances integrating the buffered roads was the only way to account for those features. Where not visible on the Quickbird imagery, the roads were aligned to USGS 1996 Digital Orthophoto Quarter Quadrangle imagery to get the correct location (Figure 5).

Figure 4a. Sample where shade is obscuring the road

Figure 4b. The final extraction layer before merged with buffered roads (yellow line)

Figure 4c. The final extraction layer merged with buffered roads (red line)

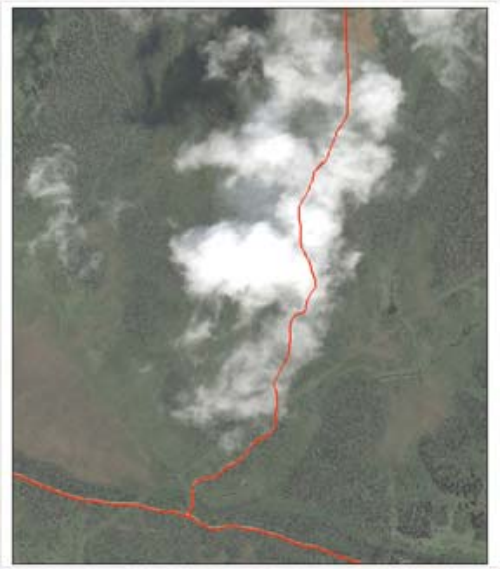


Figure 5. Cloud cover obscuring the underlying impervious surfaces.

Impervious Cover Results

The final step was to calculate the percentage of impervious cover for each watershed and sub-watershed (Table 1). Impervious cover ranged from 0.06 % in the North Fork Deep Creek sub-watershed to 2.53% in the Gamma Ninilchik River sub-watershed. Stariski Creek watershed had the greatest percent of impervious cover at the watershed scale. See Appendix 1 for impervious cover maps.

Table 1. Percent of watersheds and sub-watersheds covered in impervious surfaces.

5th level watershed	**6th level watershed**	**Watershed area** (miles^2)	**Impervious area** (miles^2)	**Impervious cover** (%)
Ninilchik River		137.5	1.66	**1.20**
	Alpha	53.1	0.49	0.92
	Gamma	22.5	0.57	2.53
	Beta	62.0	0.60	0.97
Deep Creek		218.2	1.57	**0.72**
	North Fork Deep Creek	38.0	0.02	0.06
	Cytex Creek	57.9	0.16	0.27
	Clam Creek	21.4	0.19	0.90
	Gamma-Deep Creek	33.5	0.51	1.53
	South Fork Deep Creek	67.4	0.69	1.02
Stariski Creek		52.1	0.82	**1.57**
Anchor River		224.8	2.60	**1.16**
	East Anchor River	65.2	0.08	0.12
	Chakok River	38.1	0.42	1.09
	North Fork Anchor River	30.9	0.74	2.39
	Beaver Creek	20.0	0.06	0.28
	Twitter Creek	15.7	0.18	1.15
	West Anchor River	55.0	1.13	2.06

Correlation Methods

Spearman's rank coefficients were used to determine which water quality, water quantity, land use, and macroinvertebrate variables were related to percent impervious cover. Mean values from baseline water quality and quantity data collected by Cook Inletkeeper from 1998 – 2004 were used as response variables (Mauger, 2004). Parameters included water temperature, dissolved oxygen, pH, conductivity, turbidity, color, orthophosphate, total phosphorus, ammonia, nitrate-nitrogen, and discharge. River mile and land use data (land ownership, roads, timber harvest, wetlands) from the Kenai Peninsula Borough and the Kenai Watershed Forum were used to see if specific land-uses were correlated to impervious cover. Macroinvertebrate data from five sites were collected in 1997 and 1999 by the Environment and Natural Resources Institute (ENRI) at University of Alaska Anchorage and, in 2003-2005, by Cook Inletkeeper (Mauger 2005). Five community metrics (total taxa, % EPT taxa, % EPT abundance, % Chironomidae abundance and Fine Sediment Biotic Index) were evaluated for response to impervious cover.

Correlation Results

The percent of impervious cover in a sub-watershed was positively correlated to water temperature and turbidity; however, all three of these variables were also negatively correlated with river mile as measured from the river mouth (Table 2). Temperature and turbidity tend to increase downstream naturally. Coastal watersheds tend to be developed most densely around river mouths; therefore the amount of impervious cover is likely to increase downstream also. Other water quality parameters examined were not correlated to impervious cover.

Table 2. Spearman's rank correlations (rho) for a subset of water quality and quantity variables examined on lower Kenai Peninsula salmon streams.

Parameters	Water Temperature	Turbidity	Impervious cover	River mile	Discharge
Water Temperature	1.000				
Turbidity	.583	1.000			
Impervious cover	** .830	* .783	1.000		
River mile	**-.782	* -.717	* -.697	1.000	
Discharge	* .648	.467	.442	**-.818	1.000

* Correlation is significant at the p = .05 level.
** Correlation is significant at the p = .01 level.

Roads (miles paved and/or unpaved), number of road crossings, and percent of land in private land ownership were significantly correlated with the amount of impervious cover in a sub-watershed (Table 3). Wetland area and the percent of land in timber harvest were not correlated to impervious cover; however, timber harvest was significantly correlated to total road miles, particularly unpaved roads, and road crossings.

Table 3. Spearman's rank correlations (rho) for land use variables examined in relation to impervious cover.

Parameters	**Impervious cover** (%)	**Total roads** (miles)	**Paved roads** (miles)	**Unpaved roads** (miles)	**Road crossings** (#)	**Private land** (%)	**Wetland area** (%)	**Timber harvest** (%)
Impervious cover	1.000							
Total roads	* .536	1.000						
Paved roads	**.883	* .539	1.000					
Unpaved roads	* .518	**.996	* .516	1.000				
Road crossings	**.731	* .593	**.755	* .590	1.000			
Private land	**.796	.175	**.740	.168	.493	1.000		
Wetland area	.032	-.371	.050	-.364	.324	.139	1.000	
Timber harvest	.475	**.756	.347	**.774	* .533	.027	-.288	1.000

* Correlation is significant at the p = .05 level.
** Correlation is significant at the p = .01 level.

EPT taxa (i.e. number of mayfly, stonefly, and caddisfly taxa combined) and Fine Sediment Biotic Index (FSBI: higher value means greater number of sediment intolerant taxa) were negatively correlated to impervious cover in the 1999 and 1997 data; however, not correlated in the 2003 – 2005 data. In October and November 2002, the lower Kenai Peninsula experienced two 100-year flood events. Channel scour, bank erosion and major habitat alteration reshaped salmon stream channels and riparian habitat. Samples from 2003-2005 appear to reflect these catastrophic events. Other metrics were not correlated to impervious cover before or after the floods.

Discussion and Recommendations

Impervious Cover Method

Overall the impervious surface classification worked best in non-wooded landscapes, such as wetlands and logged areas. Surfaces obscured by trees and/or shade were not picked up. Clouds in the imagery also masked areas where the training sets were not able to be applied. Black and brown roofs also often blended in with surrounding vegetation and were hard to distinguish.

Since the minimum mapping unit (mmu) was 100 ft^2, many small structures and/or cars were missed. Lowering the area of the mmu would have introduced too much noise causing extensive cleanup while not necessarily improving the accuracy. As a result features smaller than 10' x 10' were not pulled out with this method.

When integrating the buffered roads it was sometimes difficult to distinguish between roads and snowmobile trails or seismic lines. The general rule of thumb followed was to incorporate features that were missing surface vegetation on the Quickbird imagery. Many trails appear to have vegetation on the surface but look eroded in spots, possibly on hillsides. However, those highly eroded spots that follow anthropogenic features were generally pulled out by the classification.

A significant problem encountered during this project was the quality of the Quickbird imagery. The company responsible for post-processing the 2002-2003 data went through several iterations and has only come out with an adequate final product at the end of 2006. Unfortunately, the timeframe for this project did not allow us to wait until a higher quality image was available so the image on hand was used. The imagery had orthorectification problems in several locations, not fitting into the "real world" coordinates; pixel shadows, created when fusing the panchromatic imagery with the multispectral imagery where the images are not correctly orthorectified; pixels that have a striated, exploded appearance in several areas; and the fog and cloud cover that degrades the quality of the image or completely masks features.

A major recommendation in conducting a similar analysis in other Kenai Peninsula watersheds is to use the just released, final 2002/2003 Quickbird imagery or wait for LiDAR (Light Detection and Ranging) to become available. Better quality satellite imagery makes impervious surface extraction easier. LiDAR, a high resolution DEM (Digital Elevation Model), would help the analyst distinguish buildings from roads and gravel pits and pull buildings out of more rural areas. This can be done with LiDAR by integrating textures and elevations to distinguish one type of feature from another. This can be processed in conjunction with Feature Analyst using LiDAR Analyst, another ArcInfo 9.1 extension by the same company. There is an existing LiDAR image for the greater Homer area covering western Anchor River but it only contains a bare surface elevation layer and a first return elevation layer and needs a second return layer to be used in LiDAR Analyst. The LiDAR that will be acquired for the entire Kenai Peninsula will include all layers and is expected to be available in 2008-2009.

Another step that would make the process more efficient is to divide the initial image into fewer images by compressing them into a MrSID file using a program from Lizardtech (http://www.lizardtech.com/). The fewer images that training sets are created for, the cleaner the product and the more efficient the process. We did not have a program that would do this and did not recognize how much more smoothly the process would go if we had. A recommended compressed file size is less than 400Mb, which would have resulted in 4 compressed images instead of 17 uncompressed images that were used.

In summary, the initial layer extracted from the imagery after creating a good training set is a relatively easy step. Just extracting impervious features without the clean up takes little time but provides a coarse quality product. This would be adequate if the analyst wants a general idea of the major and obvious impervious surfaces. The clean up process takes considerably more time and varies substantially depending on the quality of the initial training set.

Correlations

Based on previous studies in Alaska and other States, the percent of impervious cover in lower Kenai Peninsula's salmon stream watersheds (average = 1.1%) is less than the level associated with water quality and habitat degradation. However, water temperature and turbidity were correlated positively with impervious cover, but this likely reflects natural longitudinal gradients. Since coastal watersheds tend to be developed most densely around river mouths, the area of impervious cover is likely to increase downstream also.

In an effort to understand what role warming air temperatures play in warming stream temperatures, Cook Inletkeeper and the Homer Soil and Water Conservation District have collected air and water temperature data from 20 sites in the Anchor River, Stariski Creek, Deep Creek and Ninilchik River watersheds. Results from a linear regression analysis suggest a very tight relationship between water and air temperatures collected in the lower Kenai Peninsula's salmon streams (Mauger 2006). Increasing variation is apparent along the downstream profile. The relationship between air and water temperature is likely to differ from stream to stream due to varying degrees of shading, differences in the sources of water (groundwater, surface runoff) and elevation (Pilgrim et al., 1998). Longitudinal changes are expected but the degree of change will be due to natural and/or human influences (Poole and Berman, 2001). The degree of change was greatest in the Anchor River watershed.

This impervious cover analysis provides more evidence that increasing air temperatures, rather than land use activities, are having a greater influence on water temperatures since impervious cover percentages are still quite low. However, future increases in impervious cover in the lower Anchor River may help to increase the degree of change downstream already seen in the lower watershed. Also water quality, quantity and habitat responses to low levels of impervious cover may be more evident at a reach level as opposed to the sub-watershed scale. Possible human influences at the reach level include: loss of shade by removal of stream-side vegetation, lower stream flows due to water withdrawals, loss of floodplain connectivity due to channel straightening, increasing sedimentation by removal of upland vegetation, and less water storage due to wetland loss. If people have an understanding that our activities in these valuable watersheds are playing a role in increasing stream temperatures beyond the effect of rising air temperature, we are more likely to make informed decisions about how much additional stress we want to risk adding to these important salmon streams while they are undergoing significant climate change.

Impervious cover analysis is labor intensive and dependant on appropriate and high quality imagery. A surrogate variable might be useful for tracking changes annually or bi-annually. Miles of paved roads was strongly correlated with impervious cover and might be a useful substitute if road GIS layers are updated annually.

In Anchorage, Alaska streams, threshold responses were found with sodium, chloride, iron, and manganese at 4.4 –5.8% impervious area (Ourso and Frenzel, 2003). Baseline data for these parameters are not available for lower Kenai Peninsula streams. Future monitoring should consider including these parameters to see if they show a response as impervious cover increases in these watersheds.

In the future, coordination of imagery and data collection is recommended to ensure that water quality, quantity, and macroinvertebrate data are useful for impervious cover analyses. Impervious cover analysis should be undertaken again in 5 – 10 years in this fast-growing region, and monitoring work should be planned to provide data for the same time period as the new imagery. And, for this 2002-2003 baseline analysis to be most valuable, future impervious cover assessments should be scheduled and planned.

References

Arnold, C. and C. Gibbons. 1996. Impervious Surface Coverage, The Emergence of a Key Environmental Indicator. Journal of the American Planning Association. 62(2): 243-256.

Bell, M.C., 1973. Fisheries handbook of engineering requirements and biological criteria: Portland, Oregon, United States Army Corps of Engineers.

Mauger, S. 2004. A preliminary water quality assessment of lower Kenai Peninsula salmon-bearing streams. August 1998 – June 2004. Homer Soil and Water Conservation District and Cook Inletkeeper. Homer, Alaska. 71 p.

Mauger, S. 2005. Lower Kenai Peninsula's Salmon Streams: Annual Water Quality Assessment. July 2004 - September 2005. Homer Soil and Water Conservation District and Cook Inletkeeper. Homer, Alaska. 62 p.

Mauger, S. 2006. Water quality concerns on lower Kenai Peninsula's salmon streams: Temperature, turbidity and phosphorus. Homer Soil and Water Conservation District and Cook Inletkeeper. Homer, Alaska. DRAFT.

Ourso, R.T. and S.A. Frenzel. 2003. Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska. Hydrobiologia 501: 117-131.

Pilgrim J.M., X. Fang, and H.G. Stefan. 1998. Stream temperature correlations with air temperatures in Minnesota: Implications for climate warming. Journal of the American Water Resources Association. 34:1109-1121.

Poole, G.C. and C.H. Berman. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management. 27: 787-802.

Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*. 1(3): 100-111.

Acknowledgements

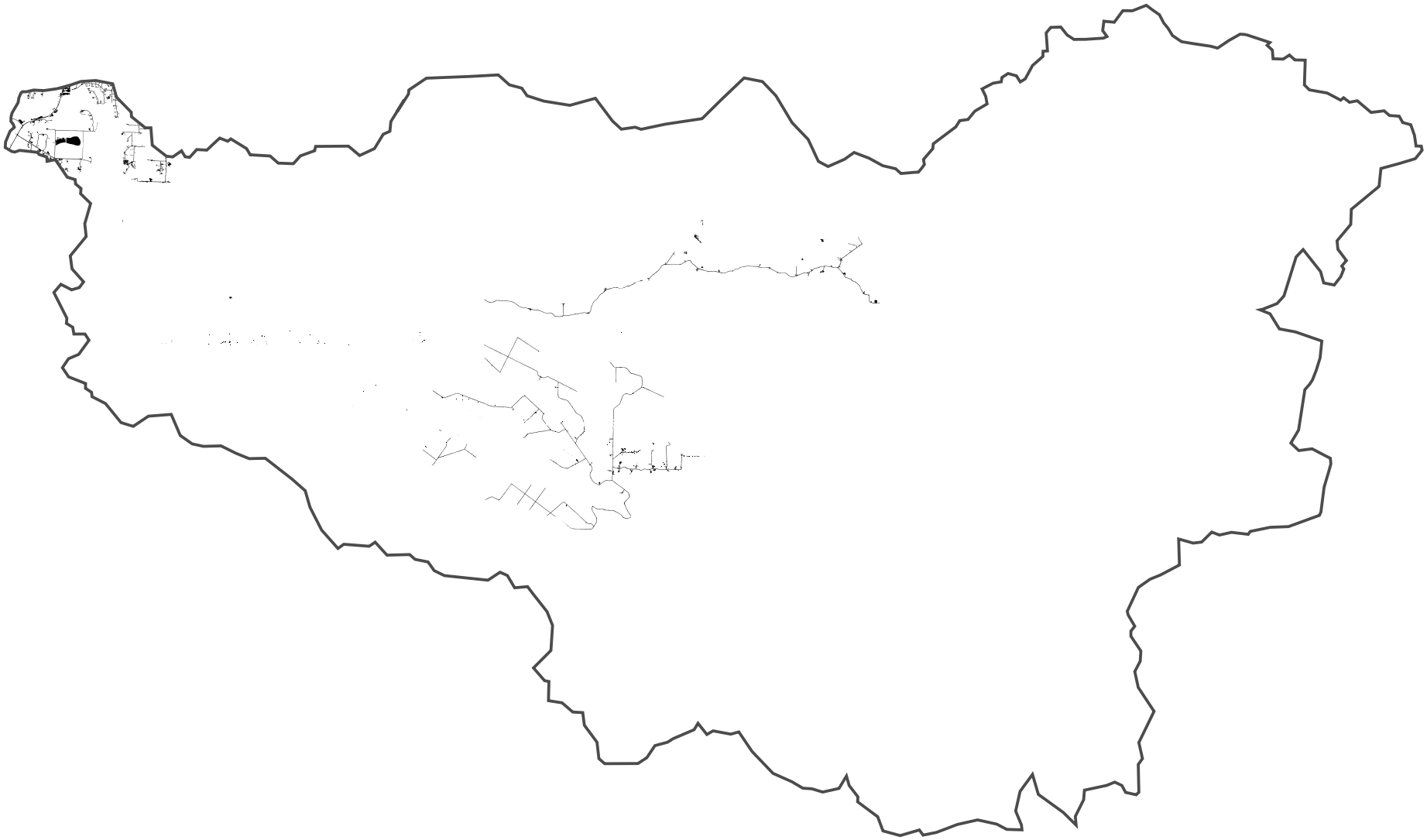
This project was made possible by the U.S. FISH AND WILDLIFE SERVICE. Cook Inletkeeper thanks Stephanie Sims at the Kenai Watershed Forum for her expertise and patience; Jason Geck and Doug Jewell from Alaska Pacific University, Alan Baldivieso at Alaska Center for the Environment, and all the responders to GIS listserv inquiries for assistance in determining the best impervious surface extraction methods. Baseline data used in this report have been generated in partnership with the Homer Soil and Water Conservation District through EPA Section 319 Clean Water Act grants from Alaska Department of Environmental Conservation, funding from Alaska Conservation Foundation, Skaggs Foundation, Alaska Oceans Program, and Patagonia. Generous support was also provided by Cook Inletkeeper's members and business supporters.

Appendix I

Impervious Cover Maps

- Ninilchik River Watershed
- Deep Creek Watershed
- Stariski Creek Watershed
- Anchor River Watershed

Deep Creek River Watershed Impervious Surfaces



0 1 2 Miles

2005 state designated anadromous streams

Subwatershed boundaries

Impervious surfaces

Data and maps made for Cook Inletkeeper by the Kenai Watershed Forum
Data in North American Datum 1983 State Plane Zone 4 projection.