Project Title: Response of an Arctic Freshwater Ecosystem to Climate and Land-use Change

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Total Funding Requested from Arctic LCC: $531,119.00

Total Leveraged Contributions: $175,347.00

1.0 Study Plan Summary

Our initial proposal focused on the Fish Creek Watershed (FCW) targeting four related landscape-level themes: (1) aquatic habitat connectivity, (2) stream and lake temperature, (3) availability of freshwater habitat, and (4) trophic mismatches. During our interdisciplinary planning workshop, the natural linkage among these topics clearly emerged as surface-water availability, connectivity, and temperature operating as a coupled system that physically mediate habitat and trophic dynamics of Arctic freshwater ecosystems. These interrelated processes form a shifting mosaic of freshwater habitats across the landscape that can be classified, mapped, understood, and modeled in response to past and future climate and land-use change in a spatial and temporal context. Developing scenarios of freshwater habitat change in this context provides managers and scientists with a flexible template to evaluate a range of potential responses to climate and land-use change. Applying this approach in the FCW is made feasible because of the availability of pre-existing geospatial and monitoring datasets and is immediately relevant to management because of ongoing and planned subsistence and industrial activities. Focusing on this watershed additionally leverages ongoing studies being supported by the Bureau of Land Management, U.S. Fish and Wildlife Service, U.S. Geological Survey, University of Alaska Fairbanks, and the National Science Foundation, along with industry sponsored studies. This study will use a phased approach resulting in an integrated landscape-scale and spatially explicit model template for managers, scientists, and other stakeholders, which can be enhanced through more focused biological studies that are already being planned. Our intent is that this project will lead to a complementary study addressing even more complex linkages among climate change, physical drivers, and nutrient dynamics and productivity responses that will be submitted to the NSF – Ecosystem Studies Program in January 2013. The research plan outlined in this proposal will be implemented by a diverse interdisciplinary team of scientists that includes climatologists, hydrologists, geographers, ecologists, fish and wildlife biologists with both basic and applied science experience in the Arctic.

2.0 Background and Justification

Freshwater ecosystems of the Arctic Coastal Plain (ACP) are dominated by lakes and ponds, wetlands, polygonized tundra, and connecting stream and river networks. Dynamic regimes of connectivity, temperature, and productivity respond to seasonal patterns of snowmelt and ice-out and summer meteoric water balance to freeze-up and ice growth (Bowling et al. 2003, Woo and Guan 2006, Lesack and Marsh 2010). Yet these regimes can be strongly asynchronous at the landscape scale within a watershed, creating a shifting mosaic of freshwater habitats as lake ice melts and snowmelt floods and drains lakes and wetlands at varying rates in space and time (Arp et al. 2011). Long-distant migrant waterbirds and locally migrating fish navigate and capitalize on this shifting freshwater mosaic according to availability (e.g., ice-cover and water depth) and connectivity, but also in response to less understood patterns in temperature and productivity (Rouse et al. 1997, Hershey et al. 1999, Lesack and Marsh 2010). For example broad whitefish (*Coregonus nasus*) and Arctic grayling (*Thymallus arcticus*), both important subsistence resources, move from river channel mainstems to large shallow lakes to feed on early summer zooplankton blooms following breakup (Morris 2003). Yellow-billed (*Gavia adamsii*) and red-throated (*G. stellata*) loons likely select lakes that best suit their different life history traits including optimum water-levels regimes allowing both nesting sites and connectivity regimes supporting an influx of forage fish. Much of the biologically-relevant landscape heterogeneity in freshwater habitats is due to water depth relative to ice thickness that determines ice regime (i.e., bedfast- vs. floating-ice) and watershed position that determines surface connectivity (Burn 1995, Lesack and Marsh 2010, Arp et al. 2011). Over longer timescales this distribution and abundance of freshwater habitat has evolved with geomorphic processes, such as thermokarst lake expansion and drainage (Jorgenson and Shur 2007), thaw pit coalescence and beaded stream formation (Jorgenson et al. 2006), and eolian and riverine processes, which locally can alter freshwater habitats rapidly and may fundamentally reshape the Arctic freshwater landscape in a changing climate (Smith et al. 2005, Lawrence et al. 2008, Grosse et al. 2011).

The ecosystems and landscape of the Arctic will respond to climate change in a variety of complex ways that directly relate to increases in air and permafrost temperature (Hinzman et al. 2005, Kaufman et al. 2009, Romanovsky et al. 2010), sharp declines in sea ice extent and duration (Stroeve et al. 2007), earlier snowmelt (Stone et al. 2002) and lake (Duguay et al. 2006, Arp et al. 2011) and river (Prowse et al. 2011) ice out, and hydrologic intensification (Rawlins et al. 2010). Clear examples of such responses include accelerating rates of coastal erosion along the western Beaufort Sea coast (Jones et al. 2009a), enhanced export of sediment and nutrients from thaw slumps along rivers (Bowden et al. 2008) and lake bluffs (Kokelj et al. 2009), thinning lake ice and shifting lake regimes (Arp et al. 2012a), and glacial retreat (Nolan et al. 2005). Many other studies present evidence of ecosystem responses to climate change such as lake drying and drainage (Smith et al. 2005, Riordan et al. 2006), exceptional tundra fires (Jones et al. 2009b), active layer thickening (Liu et al. 2010), and degradation of polygonized tundra (Jorgenson et al. 2006), yet the scale (time and space) of these observations and lack of exact identification of driving mechanisms makes understanding the scope of such responses difficult. Even more difficult is linking shifts in habitat and biological processes and populations to physical responses driven by changing Arctic climate (e.g., Flint et al. 2008). A lack of current understanding of the linkages among climate change, physical drivers, and biological responses at relevant scales presents managers and other stakeholders with great uncertainty (Streever et al.

2011). This point was highlighted by Post et al. (2009) suggesting the need to understand landscape heterogeneity as a buffer against Arctic climate change.

A recent analysis of the Fish Creek Watershed (FCW) focused on understanding landscape heterogeneity in freshwater ecosystems and the linkage to physical drivers (Arp et al. 2012b) by capitalizing on existing geospatial and monitoring datasets as part of the Fish Creek Watershed Observatory (FCWO) (Whitman et al. 2011). The sub-basins of FCW represent a natural physiographic gradient of deltaic, lacustrine, riverine, and eolian landforms which, combined with long-term (decadal) climate and river discharge observations make this landscape an ideal setting to advance our understanding of Alaskan Arctic Coastal Plain (ACP) landscape processes. Science applied towards industrial (oil and gas) development and subsistence harvest concerns in the lower FCW has similarly advanced our understanding of fish distribution and migration (Morris 2003, Heim et al. 2012), food web dynamics (McFarland et al. 2012), and lake and permafrost processes (Jorgenson et al. 2006, Jorgenson and Shur 2007). Petroleum development planned for the lower reaches of the FCW represent the establishment of permanent infrastructure in the National Petroleum Reserve-Alaska (NPR-A) for the first time since its establishment in the 1970s. In response to this planned development the BLM, USGS, and UAF have been collecting baseline datasets to describe natural variability of freshwater ecosystems in order to assess any impacts of development activities, such as lake water extraction, temporary and permanent roads, drilling pads, or enhanced dust or contaminants. Thus, potential landscape changes associated with oil and gas development allows for an assessment of the combined impact of climate and land-use change on freshwater ecosystem dynamics.

An example of research linking climate change, physical drivers, and habitat responses relevant to land-use impacts is a recent study documenting a shift in ACP lake regimes due to thinning ice that is driven by increasing early winter snowfall and temperature in a portion of the FCW (Arp et al. 2012a). In this study, a time-series analysis of synthetic aperture radar (SAR) were used to map the interannual variability in those FCW lakes that could provide over-winter fish habitat to show if, where, and when these habitats have changed during the last 9 years. This project would follow a similar approach by linking temporal habitat dynamics with spatial distributions, but take this several steps further by considering multiple habitat types and using models to make future predictions and explore various scenarios of environmental change. This type of approach that couples classification and mapping with process models provides managers and other stakeholders with a simple but comprehensive view of environmental change in time and space that can be applicable to both local and regional planning. Such a research framework will foster the Arctic Landscape Conservation Cooperative's objective of providing reliable forecasts of future conditions under various climate and land use change scenarios, so that managers may incorporate these considerations into decision making processes.

3.0 Interdisciplinary Study Objectives

3.1 Characterize the type and distribution of freshwater habitat

The FCW encompasses a diverse mosaic of freshwater habitats. At the landscape-scale, the abundance and distribution of these linked ecosystems appears to be geographically organized by

landscape processes that include the (1) delta, (2) river corridors, (3) marine sediment lowlands, and (4) eolian sand uplands (Figure 1). Freshwater ecosystems will be characterized according to local processes controlling hydrologic, thermal, and productivity regimes and corresponding habitat connectivity and availability. This effort will result in a classification system and map describing the abundance and distribution of freshwater habitats that will serve as a template for subsequent phases of this study, future related studies in the FCW, and as a model for similar classification of the broader Alaskan Arctic Coastal Plain.

Hypothesis 1: Freshwater habitat types are unevenly and disproportionally distributed across the landscape and this directly relates to the present distribution and abundance of fish and waterbird assemblages.

Hypothesis 2: Habitat types can be functionally characterized by connectivity, morphology (depth and surface area), sediment type, drainage area, and age because these characteristics determine hydrologic, thermal, and productivity regimes and corresponding suitability for fish and waterbird assemblages.

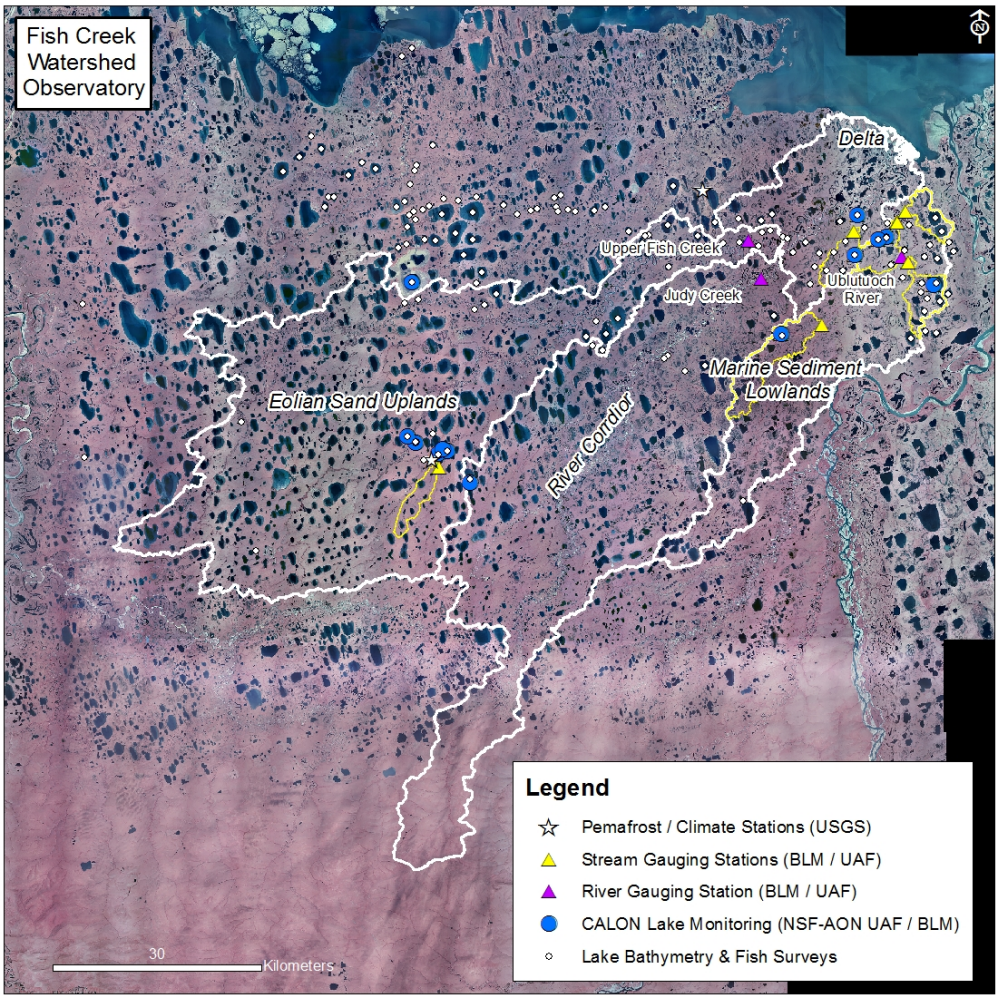

Figure 1. Map of the Fish Creek Watershed, major sub-basins, and current monitoring infrastructure with landscape process regions indicated.

3.2 Understand hydrologic connectivity and water temperature regimes and their relation to freshwater habitat availability

Individual freshwater habitats respond differently to regional climate forcing. The suitability of freshwater habitat for assemblages of fish and waterbirds is intimately related to patterns of connectivity, thermal, and productivity regimes. At the landscape-scale, the availability of optimum habitats for specific biota changes through the winter according to snow and ice regimes and through the summer according to ice-out timing and snowmelt runoff followed by evapotranspiration relative to precipitation. These seasonal regimes drive thermal and productivity optima among freshwater habitats that shift rapidly across the landscape. Fish and bird assemblages migrate, forage, and reproduce in response to these seasonal and landscape patterns, such that understanding these physical linkages is essential for predicting distribution, abundance, and success of specific biota. This phase will link the freshwater habitat classification and mapping in *3.1* with habitat-specific climatic, hydrologic, and biological processes to explain contemporary fish and waterbird distribution and abundance in the FCW. This spatially explicit process integration will take the form of both conceptual and physically-based models to test the following hypotheses.

Hypothesis 3: Freshwater ice regimes discriminate winter habitat availability for fish assemblages and aquatic food webs, and set the stage for early summer thermal and productivity optima.

Hypothesis 4: Timing and magnitude of snowmelt runoff and ice-out determines the onset, extent, and duration of freshwater habitat connectivity and thermal regimes that fish and birds respond to in selecting optimum habitats.

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Hypothesis 5: Timing and magnitude of rainfall runoff relative to evapotranspiration determines summer water balance and corresponding connectivity and thermal regime of freshwater habitats that regulate habitat availability and suitability.

3.3 Develop scenarios of freshwater habitat change as a function of environmental change

Climate change predictions for the Arctic present a number of very different potential responses with respect to freshwater habitats because of competing processes and landscape heterogeneity. Policy-makers and managers concerned with land and water resources often must assess a wide range of future outcomes and corresponding uncertainty either for site-specific projects or at the landscape-scale related to industry, subsistence harvest, and/or conservation issues. Thus, using models to analyze scenarios that can couple freshwater habitat responses with both climate change and land-use activities provides a mechanism to reduce complexity and target emerging issues. The following hypotheses have been identified to address freshwater habitat dynamics relative to both climate change and land-use anticipated for the FCW. The classification template in *3.1* and physical process observations and model development in *3.2* allow this phase of scenarios testing to be conducted at multiple spatial and temporal scales.

Hypothesis 6: Dry summers will disconnect stream-lake systems such that traditional fish migration patterns are interrupted, resulting in lower reproductive success and over-winter survival and altered lower trophic dynamics and forage base.

Hypothesis 7: Higher snowfall and wetter summers will lead to expanded connectivity and over-winter habitat in previously isolated systems that expands the availability of fish and bird habitat and alters the forage base and competition among these species .

Hypothesis 8: More winter water extraction will increase lake storage deficits resulting in altered runoff regimes and reduced connectivity throughout critical fish and waterbird migration and feeding periods.

Hypothesis 9: Earlier snowmelt and ice-out timing driven by warmer springs and road dust will cause a more rapid peak in freshwater temperatures and related productivity that will change habitat and forage availability relative to traditional fish and bird migration timing.

4.0 Technical Approach and Methods

4.1 Characterize the type and distribution of freshwater habitat

The unit of freshwater habitat we will initially focus on for this study are water bodies (>0.1 hectares) derived from orthophotography and radar imagery including wetlands in the form of drained thermokarst lake basins (DTLBs) (Frohn et al. 2005). Lake basins can be readily discretized and mapped for this purpose. Stream and river channel habitats will be linked to water bodies by degrees of connectivity to this drainage network following analysis by Arp et al. (2012b). These freshwater habitats within the FCW will initially be characterized and classified using existing geospatial data derived from aerial photography, IfSAR DEM, Landsat TM, and Advanced Synthetic Aperture Radar (ASAR) including previous hydrographic datasets (i.e., National Hydrography Dataset) and landscape classifications of surface geology and permafrost characteristics (Jorgenson and Shur 2007, Jorgenson et al. 2008). We envision three levels of classification for freshwater habitats: (Level 1) geographical distribution by landscape processes with potentially four classes (deltaic, riverine corridor, marine sediment lowlands, and eolian sand uplands) (Figure 1), (Level 2) water body depth relative to maximum ice thickness with four classes (ephemeral, shallow with bedfast-ice, shallow with floating-ice, and deep with floating-ice), and (Level 3) surface-water connectivity with four classes (isolated, headwater ephemeral, headwater perennial, and flowthrough). A prototype of this basic classification system has been completed for larger water bodies in the FCW (Arp et al. 2012b) that does not include Level 1 and several classes of both Level 2 and 3. This proposed classification could result in as many as 64 freshwater habitat classes, yet we expect this number will be much smaller because of the association of landscape processes with depth and connectivity. We intend this phase to be completed by late 2013 and will be co-led by Arp and Jones.

At the completion of this initial freshwater habitat classification, a subset of sites from each class will be selected for field sampling characterization and time-series remote sensing analysis. Additionally, this characterization subset will be based to the extent possible on sites where inventory and monitoring activities have historically occurred or are ongoing such that we can fully utilize existing datasets for habitat characterization. Synoptic field measurements and sampling will be conducted in mid-April, late June, and mid-August of 2014 to measure water depth, discharge, and water quality parameters and collect water samples for stable isotopes, chlorophyll a, and plankton analysis. Sediment and basal peat samples will also be collected at a

subset of sites to evaluate long-term habitat evolution and productivity (led by Gaglioti and Grosse). Fish survey (presence / absence and biometrics) and bird surveys (arrival time and presence absence) may also be completed on a subset of these water-bodies (led by Whitman and Wipfli, and Nigro, respectively). Existing fish surveys in FCW and the adjacent region will also be organized in a geospatial database to support analysis of fish communities and foraging habitat for piscivorous waterbirds (fish technician with oversight from Whitman and Wipfli). Remote sensing time-series analysis will focus on documenting patterns in surface-area and stream connectivity expansion and contraction and productivity regimes using historic high resolution satellite imagery (i.e., Corona, Hexagon, Quickbird, Geoeye, Worldview 2, and Ikonos). Together these field and remotely sensed measurements will be compared to the initial classification to determine whether this system needs to be further refined or potentially several classes regrouped. Field surveys will be led by Arp and remote sensing analysis will be led by Grosse.

The result from this characterization phase will be a map of the FCW showing each freshwater habitat unit and corresponding key describing class characteristics (hard copy map and geospatial database). Sites with field data or remote sensing time-series analysis will be indicated on the map and referenced in a table and report.

4.2 Understand hydrologic connectivity and water temperature regimes and their relation to freshwater habitat availability

The primary means of accomplishing this objective will be to select individual sites (stream-lake or stream-wetland systems) that represent the major freshwater habitat classes, fully quantify site connectivity, thermal, and productivity regimes, and develop physically-based models of these systems. Site regime analysis and models will be based on higher resolution geospatial data and monitoring datasets and used to analyze the range of seasonal and interannual variability in water balance (depth and surface-area extent), connectivity (channel flow and tundra inundation), and water temperature. Though ideally regime analysis and model development would include all 64 potential freshwater habitat classes, based on our experience in the watershed, we believe that a more realistic goal is to select 12 sites that capture the majority of these classes.

Through existing baseline monitoring programs (BLM's Fish Creek Watershed Observatory and NSF-AON CALON Project) focused at the small catchment and lake scale (1 – 50 km^2), we expect to have the appropriate datasets available for 9 of 12 sites (Figure 1). New sites would most likely be located in the delta region (two sites) and a DTLB in the eolian sand upland region (one site) with instrumentation and field surveys to monitor water levels, water temperature, and discharge. Additional instrumentation to calibrate field sampling and remote sensing of chlorophyll a (proxy of primary productivity or phytoplankton abundance) will include use of water quality sondes that would be rotated among several sites during key periods in each of the study years (fieldwork led by Arp and Whitman and remote sensing by Grosse in coordination with Wipfli).

Regional historic and future climate data used for regime analysis and model forcing for this study will be developed from a limited area climate model Weather Research and Forecasting (WRF) (Michalakes et al. 2005) at 3-5 km horizontal resolution driven by existing reanalysis products (NCEP/NCAR (Kalnay et al. 1996), ERA-Interim (Uppala et al. 2005) or NARR (Mesinger et al. 2006)) and decadal climate projections using NCAR's Community Earth System

Model (CESM) that are currently in production by NCAR and will be soon made available to the community (led by Alexeev). WRF output after calibration and adjustment for biases using all possible variety of available observations will be used for driving the more detailed permafrost/hydrology and snow models. Regional-scale historic and future snow distribution modeling will be developed using SnowModel and associated data assimilation models at 1 km horizontal resolution (led by Liston) and site-scale historic and future snow distribution modeling will be developed at 5-m scale that accounts for vegetation and microtopography (led by Hiemstra). The latter snow model will require field snow surveys for each site. Both climate and snow modeling efforts will be greatly strengthened by two existing weather stations (USGS GTN-P) in the FCW in operation since 1998 and several shorter term climate records from USGS, UAF, and BLM, along with snow surveys in the lower portion of FCW since 2006 and upper portion of FCW since 2012 (Figure 1).

Our ideal site (freshwater habitat class) modeling framework is the physically-based hydrologic model WaSiM-ETH (Schulla 1997) to represent water balance, basin spill and fill dynamics, connectivity, ice dynamics, active layer dynamics, and thermal regimes. WaSiM-ETH minimum input requirements include a digital elevation model, vegetation and soil maps, precipitation and air temperature, and is improved by wind speed, vapor pressure, and shortwave incoming radiation, representing a reasonable compromise between detailed physical basis and minimum data requirements. This component would be led by Liljedahl and Daanen who have used this model at a high spatial resolution to represent polygonized tundra environments in Barrow and are working to incorporate 2-D heat transfer coupled to the unsaturated and saturated soil zone through the recently funded Department of Energy NGEE Project. Model development for the FCW freshwater habitat analysis will be run at a spatial scale to capture the dominant hydrologic features of interest (lakes, lake basins, and beaded streams) for domains ranging from 5 – 50 km^2. To fully implement this approach, we are seeking outside funding from the Alaska Climate Science Center to support a graduate student to work with Liljedahl to develop, test, and calibrate this modeling approach for the FCW. An alternative strategy will be to use a simpler lumped 1-D modeling approach for each study site to represent water balance (lake levels and extent), and stream flow and connectivity described in Arp et al (2011) and an empirical lake thermal model that has been implemented and tested on ACP lakes (Arp et al. 2010). Following this method, model experiments using WaSim-ETH would be run to capture and simulate the essential freshwater habitat class configuration and understand system interactions in synthetic terms (Liljedahl et al. 2012). Both modeling options, coupled with regime analysis, can be used to examine hypotheses 3-5.

The result from this analysis and modeling phase will be conceptual and quantitative descriptions, hindcasts, and forecasts for each freshwater habitat class, which will be linked to the classification and mapping effort in phase 1 (report describing past, present, and future regimes and interannual variability). It is our intent that this phase will serve as a template for more targeted biological studies to understand migration of subsistence fishes (i.e., broad whitefish) and habitat use by waterbirds of conservation interest (i.e., yellow-billed loons).

4.3 Develop scenarios of freshwater habitat change as a function of environmental change.

The strength of developing a spatially explicit model template for the FCW is that it couples a spatial distribution of freshwater habitat classes to physically-based representations of ecosystem behavior that can be used to test a variety of scenarios and as new climate feedbacks or land-use

concerns emerge. This scenarios process is described according the following examples that correspond to our original hypotheses.

Example 1: For this scenario, consecutive dry summers could be represented by the annual climate data from 2007 (extreme drought year) run repeatedly over many years to simulate the effect of multiyear drought on lake water balance, ice thickness relative to water depth, streamflow and temperature regimes, and connectivity for several models of freshwater ecosystem classes (e.g., perennial headwater lake (shallow floating-ice) in marine silt lowlands). For example, the timing and duration of stream-lake disconnections could be compared to the known timing of migration for broad whitefish. Reduced water balance generated by prolonged drought could cause a shift to bedfast-ice conditions, eliminating over-wintering stickleback (important forage fish) habitat for a particular habitat class and potentially disrupting summer forage for Arctic grayling and yellow-billed and red-throated loons. Conversely, running the same drought simulation for another habitat class, such as a flowthrough lake (shallow floating-ice) in eolian sand, may show the system remains connected during critical migration periods and maintains over-winter habitat to support continued grayling and loon forage. Managers could use this information to determine which lakes within a region could be safely permitted for industrial winter water supply following a dry summer, when the next year's conditions are uncertain.

Example 2: For this scenario, snowfall and rainfall could be increased by 25% above average for a 10-year model run to simulate the effect of wetter conditions on lake water balance, ice regimes, water temperature, and connectivity to the downstream drainage network. For an isolated (bedfast-ice) lake in the marine sediment lowlands, this form of climate change could cause prolonged immigration (early spring) and emigration (late summer) of both stickleback and grayling and a shift to floating-ice conditions allowing more over-winter habitat. This could increase the abundance of fish habitat in this region (marine sediment lowlands), but also increase competition with aquatic invertebrate feeding birds such as the red-necked phalarope. Conversely, the same climate change scenario run for an isolated (bedfast-ice) lake in eolian sand uplands may show that connectivity is not altered because of greater channel substrate porosity that only allows subsurface flow even in wetter conditions. Managers could use this information to permit, for example, more water extraction from some fish-bearing lakes in the lower watershed, while maintaining similar levels of water extraction in the upper watershed. Another example is, knowing that increased competition between fish and planktivorous waterbirds may help explain demographic shifts or population declines in these waterbird populations that may be observed.

Example 3: For this scenario, varying lake water extraction rates could be simulated for each floating-ice freshwater habitat class (isolated, headwater, and flowthrough) in the eolian sand uplands where new exploration and corresponding ice-road permits are being considered. The frequency and timing of connectivity for each habitat class could be simulated over varying snowmelt recharge amounts. Based on simulated connectivity regimes for each habitat class, lake pumping volumes could be modified to protect fish migration routes to certain forage lakes, as well as maintaining water levels of shoreline feeding areas for waterbirds. Another application could be to modify water extraction volumes for certain sensitive lakes in a habitat class if below average snowfall occur in a particular year.

Example 4: For this scenario, the response of all freshwater habitat classes to an extremely warm spring would be simulated in terms of thermal regimes and corresponding primary productivity (phytoplankton blooms) of streams, lakes, and wetlands. The timing of these peaks and productivity curves could be compared to known traditional fish migration and waterbird arrival timing to look for potential trophic mismatches in forage availability. Based on this analysis, particular bird or fish species may be identified as sensitive to forage limitations during extremely warm springs and targeted studies (fish telemetry or bird growth and reproductive success) may be implemented to determine if additional habitat or species conservation measures are warranted. Similarly, the simulation of water temperature regimes in this scenario could be used to identify which freshwater habitats are more sensitive to exceeding thermal limits during warm spring conditions, providing a landscape map of thermal refugia for certain fishes and waterbirds in a warming Arctic climate. Such an analysis could aid scientists and managers in predicting changing distributions of fish and waterbird communities within the FCW and broader regions of the Arctic Coastal Plain. The role of road dust in an area of industrial activity in relation to snowmelt timing and runoff could also be evaluated and lead to the implementation of new Best Management Practices (BMPs).

5.0 Education and Outreach Plan

An important part this study will be to present the results from the habitat classification and mapping and initial monitoring and modeling components to federal, state, and borough land and resource managers and other stakeholders (i.e., petroleum industry, conservation organizations). This will be accomplished initially by presenting our results at a state conference such as AWRA-AK, AFS-AK, and AK Bird Conference in year 2, after which we will schedule a two-day workshop in Fairbanks and potentially Barrow and Nuiqsut for interested managers and stakeholders in order to determine the modeling scenarios of greatest interest. Results from this workshop will feed into year 3 of the project where we finalize models and use these to simulate climate and land-use scenarios of interest to management and science issues for the FCW and more the Arctic Coastal Plain in general. We also expect to present these results in scientific journals.

6.0 Budget

6.1 Requested Budget and Narrative

Costs and budget are unofficial estimated costs for discussion only. These costs have not been reviewed or approved by the University of Alaska Fairbanks. Costs assume a start date of 1 July 2013 and an end date of 1 June 2016.

Table 1. Summary of requested budget.

Category	Year 1	Year 2	Year 3	Total
UAF				
Senior Personnel	$12,356	$11,314	$17,814	$41,484
Other Personnel	$49,395	$45,900	$30,058	$125,353
Fringe Benefits	$22,594	$21,899	$17,149	$61,642
Travel	$4,515	$4,515	$0	$9,030
Materials and Supplies	$31,000	$5,000	$0	$36,000
Publications	$0	$0	$5,000	$5,000
Logistics	$0	$50,000	$0	$50,000
Consultant Services	$15,000	$0	$0	$15,000
Sample Analysis	$10,000	$1,500	$1,500	$13,000
Planning and Outreach	$200	$200	$10,000	$10,400
Indirect	$23,636	$25,433	$15,141	$64,210
Total UAF	$158,696	$170,761	$101,662	$431,119
Collaborators				
USGS	$35,000	$20,000	$0	55,000
CRREL	$19,000	$13,000	$13,000	45,000
Project Total	$212,696	$203,761	$114,662	$531,119

Salaries

Senior Personnel. Funding to support a total of 120 hours per year for 3 years is requested for the Principal Investigator of this project, Chris Arp, who will manage the project. Funding is requested to support co-I Anna Liljedahl (170 hrs/yr), who will oversee and contribute to hydrologic and thermal model development and scenario simulations. Per UAF policy, faculty receive leave benefits at a rate of 1.7%, calculated on salary. *Requested funds: $41,484.*

Other Personnel. Funding is requested according to the table below. Per UAF policy, faculty and staff receive leave benefits at a rate of 1.7% and 21.7%, calculated on salary. *Requested funds: $125,353.*

Personnel & Responsibilities	Y1	Y2	Y3	Total
R. Daanen, 170 hrs/yr (hydrologic and thermal model development and scenario simulations)	$11,174	$5,782	$7,481	$24,437
G. Grosse, 130 hrs/yr (image acquisition and analysis to determine lake / wetland surface area, stream connectivity, and Chl a dynamics)	$6,549	$5,423	$5,613	$17,585
V. Alexeev, 160 hrs/yr (WRF modeling to produce past 50 year and next 50 years climate record for portions of FCW)	$13,988	$7,239	$7,492	$28,719
Hydro Tech, 360 hrs/y1&y2 (fieldwork and analysis of hydrologic, thermal and productivity regimes; model development and scenario simulations)	$8,842	$9,152		$17,994
Fish Tech, 360 hrs/y1&y2 (technician to sample lake fish species composition; develop fish community database)	$8,842	$9,152		$17,994
Bird Tech, 360 hrs/y2&y3 (technician to monitor and inventory bird species composition and arrival timing; characterize habitat)		$9,152	$9,472	$18,624

Fringe Benefits

Staff benefits are applied according to UAF's benefit rates for FY13, which are negotiated with the Office of Naval Research (ONR) annually. Rates are 34.1% for faculty salaries and 42.8% for staff. *Requested funds: $61,642.*

Travel

For field travel costs, see services below.

Funds are requested for project team members to meet in Years 2 & 3 to plan and discuss project activities. Meetings will be held at Chena Hot Springs Resort, outside Fairbanks, AK. Costs for meals are estimated at $52 per day for 2 days, for 10 people. Lodging costs are estimated at $250 per night for one night for 10 people. Participants will travel in personal vehicles, at an estimated cost of $.55/mile (130 miles RT) and roughly $26 per traveler in fuel costs. All pricing is based on current pricing, US Government figures, and UA Board of Regents policy. *Requested funds: $9,030.*

Other Direct Costs

Materials & Supplies. A total of $36,000 is requested for supplies, according to the table below.

Item	Y1	Y2	Y3	Total
Water-level and Temperature Sensors	$11,000	$0	$0	$11,000

Water Quality Sondes	$20,000		$0	$20,000
Water Isotope and Chlorophyll a Analysis	$0	$5,000	$0	$5,000

Publication & Dissemination. A total of $5,000 is requested to fund publication costs, to defray the expenses of publishing our results in professional journals.

Fieldwork Services. Funds of $40,000 are requested in Year 2 for helicopter access to the field sites (Inigok, AK). Another $10,000 is requested for Year 2 to transport the field crew to Nuqsuit or Inigok. *Requested funds $50,000.*

Consultant Services. Funds are requested for participation by Joerg Schulla (modeling consultant), who will contribute to hydrology tasks. *Requested funds: $15,000.*

Sample analysis. Funds are requested to support C14 analysis ($500 / sample = 20 samples) through WERC agreement; C13, N15 through INE-SIL. *Total cost to project: $13,000*

Outreach Workshops and Project Meetings. Funds of $200 are requested in Years 1 & 2 to supply a meeting space, audio-visual support, and appropriate catering (snacks) for project meetings held at Chena Hot Springs Resort, Alaska (see "travel for more details). Another $10,000 is requested in Year 3 to hold Outreach/Scenarios workshops in Fairbanks, AK for interested agency stakeholders. Funds will cover space rental, audio-visual support, and appropriate catering (snacks). Attendees will supply their own travel costs. *Requested funds $10,400.*

Indirect Costs

Facilities and Administrative (F&A) Costs are negotiated with the Office of Naval Research and for this project are calculated under the existing CESU agreement at 17.5% of the Modified Total Direct Costs (MTDC). MTDC includes Total Direct Costs minus tuition and other student support, subaward amounts over $25,000, and equipment. A copy of the agreement is available at: http://www.uaf.edu/files/osp/UA-FY-11-13-Pred-FA-Rate-Neg-Agrmt.pdf

Collaborator Funding

Collaborators at other institutions will participate in this project according to the table below. We anticipate that these funds will be awarded directly from Arctic LCC to the agencies.

Participant and Role	Estimated cost to project
Matthew Whitman, Debora Nigro (Bureau of Land Management)	None requested
Ben Jones (USGS)	$55,000
Mark Wipfli, Frank Urban (USGS)	None requested
Jeff Adams (US Fish & Wildlife Services)	None requested
Glenn Liston (Colorado State University)	None requested
Chris Hiemstra (US Army Cold Regions Research & Engineering Laboratory)	$45,000

6.2 Leveraged Contribution

Table 2. Summary of estimated in-kind contributions. *Estimated values based on low range of expected contributions from projects and not representing any formal agreements between projects.

Category	Year 1	Year 2	Year 3	Total
Senior Personnel Salary	$ 18,087	$ 18,352	$ 20,520	$ 56,958
Other Personnel Salary	$ 7,928	$ 4,611	$ 5,147	$ 17,685
Fringe Benefits	$ 8,871	$ 7,830	$ 8,753	$ 25,454
Materials and Supplies				
Fish Creek Hydrology (BLM, Arctic LCC)*	$ 25,000			$ 25,000
CALON (NSF-AON)*	$ 3,250	$ 1,000	$ 1,000	$ 5,250
Logstics				$ -
Fish Creek Hydrology (BLM, Arctic LCC)*	$ 10,000	$ 10,000	$ 10,000	$ 30,000
CALON (NSF-AON)*	$ 5,000	$ 5,000	$ 5,000	$ 15,000
Total	**$ 78,136**	**$ 46,793**	**$ 50,419**	**$ 175,347**

7.0 Integrative Management Approach, Deliverables, and Timeline

The project PI Arp will be in charge of coordinating among the team throughout the project. A two-day annual project meeting will be held at Chena Hot Springs (early November) to discuss progress, present results, and plan next tasks.

Table 1. Project tasks and workflow for three year study with expected start date of late summer 2013 and going through spring of 2016.

Task	2013	2014	2015	2016
Initial Classification and Mapping	Jones, Arp, Grosse			
Remote Sensing Characterizatin		Grosse, Jones		
Fish Inventory Database	Wipfli, Whitman, Arp			
Field Characterization		Arp, Jones, Grosse, Gaglioti Hiemstra		
Biological Surveys		Whitman, Nigro, Arp, Wipfli		

Classification and Mapping Refinement	Jones, Arp, Grosse
WRF Modeling	Alexeev
Snow Distribution Modeling	Hiemstra
Site Monitoring and Analysis	Arp, Whitman, Jones, Grosse, Hiemstra, Wipfli
Habitat Model Development	Liljedahl, Daanen
Outreach and Scenarios Workshop	All
Scenarios Development	All
Scenarios Modeling	Liljedahl, Daanen
Final Report and Outreach Presentations	Arp, Wipfli, Jones, Liljedahl

8.0 Coordination with Existing Programs

CALON (NSF-AON) - Towards a Circumarctic Arctic Lake Observation Network (CALON): Multiscale observations of lacustrine systems (2011-2014) (ARC-1107607) has a primary goal of collecting and disseminating baseline data on physical and biogeochemical processes of Arctic lakes across regional gradients. This is accomplished using nested monitoring / measurements of multi-lake nodes arrayed along two N-S transects coupled with remote sensing analysis. Two nodes (Inigok and Fish Creek) are located within the FCW. Monitoring infrastructure and datasets will be used for site characterization and model calibration.

Fish Creek Watershed Hydrology Monitoring (Arctic LCC) - The objective of this project is to maintain a network of hydrology monitoring sites in a representative watershed of the Arctic Coastal Plain. Work is being conducted within the context of climate change and impending oil and gas activities in the region, the impetus for focusing on the Fish Creek watershed. Monitoring infrastructure and datasets will be used for site characterization and model calibration.

Alpine Satellite Beaded Stream Monitoring (BLM Arctic Field Office) – The objective is to obtaining data from streams and lakes in the Fish Creek Watershed in order to provide a baseline describing seasonal regimes and interannual variability in physical processes and the role of these processes in habitat, which will assist with management decisions and help evaluate

management practices related to the protection of fish habitat among oil and gas surface activities. Fish Creek watershed. Monitoring infrastructure and datasets will be used for site characterization and model calibration.

BLM/UAF/USFWS Fish Movement and Feeding Ecology - This portion of the study is designed to gain a better understanding of the seasonal movements of Arctic grayling within Crea Creek, a representative beaded tributary stream within FCW. The objectives of the study are to determine: 1) the extent and timing of Arctic grayling movements; 2) identify environmental factors that influence these movements; and 3) describe the habitats used by these fish. With this information, follow-up studies will be designed to identify spawning, overwintering, and feeding habitats. Identification of these critical habitats will allow managers to recognize migratory corridors and prioritize actions to conserve this species in the FCW.

USGS Changing Arctic Ecosystems - All components of this work (hydrology, trophic processes, and fish and bird effects) will benefit the CAE, informing us on how these processes are similar, or different, to help us understand at the broader landscape scale how the ACP functions and how food supplies for fish and birds may change across the broader landscape. The Fish Creek project will further benefit from CAE studies through understanding how water bodies respond to heating and nutrient addition experiments taking place within the CAE project. CAE experiments include heating and fertilizing small ponds to understand how heat and nutrient release from permafrost thaw affects food resources for fish and birds. This information will be used to help develop the hydrologic models for the Fish Creek study. The stickleback manipulation experiment will further tell us how food webs respond to stickleback presence.

SNOWDATA - Understanding snow conditions is key to developing a better understanding of hydrologic, biological, and ecosystem processes at work in northern Alaska, but these data currently do not exist at spatial or temporal scales needed by end users. To address this need, the Arctic LCC and Alaska Climate Science Center have partnered with researchers from Colorado State University to produce retrospective datasets simulating snow conditions for much of northern Alaska. As part of this project, hindcast and forecasts of snow distribution at the 1 km resolution are planned for the entire Fish Creek Watershed including modeling of lake ice and lake snow.

USGS Real-time Permafrost and Climate Monitoring Network – This program has been maintaining several weather and permafrost monitoring stations in the NPR-A since 1998. These data will be essential for calibration of WRF and SnowModel and analysis of freshwater habitat hydrologic and thermal regimes.

9.0 Data Management Plan and Dissemination Strategies

The majority of monitoring data generated from this project will fall under existing data management plans for the Fish Creek Watershed Observatory and/or CALON (NSF-AON, A-CADIS). For new geospatial data and model output from climate, snow, and hydrologic simulations, a specific data management plan is being developed by personnel at Institute of

Northern Engineering (P. Prokien). This will include looking at the feasibility of utilizing the Arctic LCC funded Hydroclimate Database for management of geospatial and model simulation datasets.

10.0 Permit Requirements

All field activities will be permitted through the Bureau of Land Management Arctic Field Office. Fish sampling will be coordinated through the Alaska Department of Fish and Game (ADFG), Fish Resource Permit, and the ADFG North Slope Area Fisheries Manager.

11.0 Suggested Implementation Team

Person	Affiliation	Title / Expertise	Project Role
Chris Arp	UAF-WERC	Ecologist	PI – Team Coordination, Hydrological and ecological analysis and modeling
Anna Liljedahl	UAF-WERC-IARC	Hydrologist	Co-I – Team Coordination, Hydrological modeling
Matthew Whitman	BLM	Fish Biologist	Co-I – Fieldwork Coordination, Fisheries studies and integration
Ben Jones	USGS, UAF	Geographer	Co-I – Geospatial Analysis, Integration with field studies and modeling
Debora Nigro	BLM	Wildlife Biologist	Co-I – Bird studies and integration
Mark Wipfli	USGS, UAF	Aquatic Ecologist	Co-I – Ecological analysis, Integration of productivity and fish studies, with modeling
William Morris	ADF&G	Fish Biologist, Supervisor	Collaborator – Fish and water resources management integration
Jeff Adams	USFWS	Fish Biologist, Supervisor	Collaborator – Fish biology and subsistence integration
Ronald Daanen	UAF-WERC	Hydrologist	Collaborator – Permafrost processes and modeling
Glen Liston	CSU	Climatologist, snow scientist, modelr	Collaborator – Snow and ice modeling, senior scientist
Vladimir Alexeev	UAF-IARC	Climatologist	Co-I – Climate modeling and integration with snow and hydrologic models
Christopher Hiemstra	CRREL	Snow Scientist	Co-I – Snow modeling and field data collection, Integration with hydrologic models
Ben Gaglioti	UAF-WERC	Paleoecologist	Collaborator – Habitat history and productivity analysis
Guido Grosse	UAF-GI	Permafrost Scientist	Co-I – Remote sensing and permafrost processes analysis
Frank Urban	USGS	Geologist, climatologist	Collaborator – Climate data collection and management

*CVs can be provided if additional information of team expertise is needed.

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