CENTER for SCIENCE in PUBLIC PARTICIPATION
6601 Chevigny St., Anchorage, AK 99502
Phone (907) 242-3496 / web: www.csp2.org / e-mail: cwoody@csp2.org
"Technical Support for Grassroots Public Interest Groups"

25 June 2013

Critique of Northern Dynasty's Proposed Mitigation Strategies

By: Dr. Carol Ann Woody

Northern Dynasty Minerals (NDM) criticized EPA's recently revised Bristol Bay Watershed Assessment for not considering some potential mitigation strategies to offset lost salmon production from mining.[1] They claim mitigation works: "Large amounts of money continue to be dedicated towards the implementation of these kinds of measures because they work; this is settled science." There is indeed an inverse relationship between the number of salmon remaining in a region and the amount of money spent on their "enhancement" or "recovery". However, the fact that all U.S. Atlantic salmon populations are endangered (NMFS 2013), 40% of Pacific salmon in the Lower 48 are extirpated from historic habitats (National Research Council 1996) and 1/3 of remaining populations are threatened or endangered with extinction, clearly illustrates that mitigation is not offsetting losses to public salmon resources.

Many of NDMs proposed "mitigation" strategies are unproven and thus would be experimental. Others, such as adding wood and rocks to currently productive rivers make untenable assumptions (e.g., habitat now limits salmon production) and overlook the fact that most of the "successful" mitigation examples they cite focus only on trout or coho salmon, were undertaken in highly altered systems where rehabilitation was necessary to begin to restore pre-impact fish productivity, and that the majority of such projects are never quantitatively monitored or evaluated, especially over the long-term, thus claims of success are unproven. Because impacts from mining in Bristol Bay will be perpetual, it is important that any proposed mitigation or compensation provide proven perpetual benefits. This paper reviews and critiques mitigation strategies proposed by NDM (in italics).[2]

1. **Northern Dynasty (NDM): Water Management-** *Water from EPA's WWTP could be distributed in a manner that reflects the relative importance of certain locations and reaches of streams. For example, instead of arbitrarily distributing water from the WWTP equally to the NFK and SFK, water discharge could be appropriately distributed to the upper portion of UT where the greatest potential magnitude of benefit would accrue to coho salmon. Surprisingly, EPA chose to distribute no water into this watershed. Also, EPA could have ensured that sufficient water was distributed to the South Fork "Springs" area, which is the major salmon spawning area in the SFK.*

   RESPONSE CSP2 Woody: Northern Dynasty Mine (NDM) fish consultants claim to know where the highest densities of spawning salmon are located in each river by species; based on this knowledge they suggest 3 water management mitigation scenarios not considered by EPA. Their proposal to add water to Upper Talarik to provide the greatest "potential magnitude of benefit" to coho salmon is untenable based on data presented in the PLP EBD. Baseline studies are inadequate to estimate total number of spawning or rearing salmon because bias and precision of aerial counts or fry density by study section was never determined. Further potentially hundreds of kilometers of headwaters used by salmon were never surveyed. Thus their claim of knowing where to derive the greatest magnitude of benefit to coho salmon over

[1] Appendix B, Northern Dynasty Mine comments submitted in response to EPA's 2013 Revised Watershed Assessment.
[2] *Ibid.* page 70

time via water redistribution is unsupported. Further, they will be impacting all freshwater life stages of five species of salmon, which have different habitat needs in space and time. How will each species be proportionally affected and compensated for via water management?

The three water management scenarios suggested below are all untested under harsh Alaska environments to mitigate for lost fish habitat. NDM consultants suggest on page 19 Appendix D to:

1- ***NDM: Develop further impoundments to increase total water volume available to offset downstream flow reductions.*** RESPONSE CSP2 Woody: This option would likely increase impacts to salmon habitat through further damming of streams and impoundment creation in the region; no supporting documentation regarding efficacy of such a program for salmon mitigation is provided.

2- ***NDM: Creation of ice fields to recharge aquifers and increase available stream flows.*** RESPONSE CSP2 Woody: Authors cite three papers implying that this technique has been successfully implemented elsewhere in regards to mitigation for salmon habitat loss. However, review of citations does not support such mitigation for salmon. Clark and Lauriol (1997) is a study of natural groundwater recharge rates in a karst permafrost system of the Yukon and is not comparable to the alluvial, non-karst, non-permafrost Pebble region where such ice fields would have to be created, managed, and maintained – basically an unproven experiment with unknown outcome. Alamaro 1999 is an unpublished Masters thesis on the feasibility of generating and storing winter ice to meet summer water demands but was never published in the primary literature and is unavailable for review. Yoshikawa et al. (2007) is a study of natural ice fields and hydrology in the Brooks Range of Alaska, and provides no support regarding potential application or efficacy of ice field creation for manipulating stream flows in a mine-impacted environment.

3- ***NDM: Water pump-back systems or recirculation of downstream water upstream for re-release***. RESPONSE CSP2 Woody: The non-mine influenced examples given for where this method "works" are from the Lower 48 (LA, Colorado, etc.) in highly altered systems with endangered and threatened fish populations. How this hypothetical system would work in a unique mine-impacted hydrologic unit is unknown and untested. A potentially expensive experiment with unproven utility for mitigating mine impacts under Alaska conditions. Such systems would need power, and potentially, maintenance into perpetuity. Further, no peer-reviewed before-after studies showing statistically defensible increases in salmon production as a result of these pump back projects exist.

2. **NDM: Water Management:** *EPA chose to distribute water from their WWTP via surface discharge, which would result in violations of Alaska's Water Quality Standards and change the emergence timing of juvenile salmon, resulting in potentially catastrophic juvenile mortality. EPA should have realized that using the water available to recharge and surcharge groundwater aquifers, with aquifer residence time of generally a year or more, that provide critical stream flow would have eliminated the problems identified. In addition, the default release of WWTP water to*

recharge and surcharge aquifers would assure that WWTP upset or shutdown would not interfere with the continuing release of water to streams from groundwater storage for extended periods.

RESPONSE CSP2 Woody:

1. Manipulation of the complex groundwater hydrology documented by PLP consultants (Smith & McCredie 2008, Groundwater Hydrology-Mine; PLP Agency presentations 2008, Anchorage) to augment stream flows would be a large-scale experiment and could fail to achieve critical stream flows for salmon mitigation, particularly during Alaskan winters.

2. Developing water impoundments, ice fields, and pump back systems to mitigate for decreased natural river flows in Alaska are unproven. No scientific documentation on the success of such projects to increase salmon production is provided.

3. If impacts are perpetual then perpetual maintenance of proposed mitigation may be required.

-

2. **NDM: Water Management:** *EPA should have recognized that the WWTP discharge could be designed to provide water chemistry concentrations that would improve the buffering capacity, primary productivity, secondary productivity, and also reduce the potential toxicity of metals at area downstream of locations where discharge water reenters the stream channels.*

RESPONSE CSP2 Woody:

1. Changing the water chemistry of area streams fails to recognize basic salmon life history in that salmon imprint on natal stream chemistry (Dittman and Quinn 1996), which enables them to return to and spawn in the streams to which they are adapted. Calcium ions are considered an important odorant that allow sockeye salmon to discriminate their natal stream (Bodznik 1978). Changing stream chemistry could result in salmon not recognizing their natal stream and dying without spawning or they could stray to a stream to which they are not adapted and potentially suffer higher mortality thus lowered productivity.

2. Accurate and precise manipulation and control of stream chemistry for the large rivers that would be impacted would be a challenging difficult experiment with unknown outcome particularly during spring and fall flood seasons. And would there be water management into perpetuity?

3. **NDM: Increase Habitat Connectivity:** *EPA failed to recognize numerous opportunities in all three principal watersheds to provide fish access to existing, suitable habitats that are not currently connected to a main stem channel. Figures 5.1, 5.2, and 5.3 show representative sites in the NFK, SFK, and UT, respectively. These figures are representative of photographs displayed in the EBD in Chapters 4, 7, and 15, which EPA apparently did not review. These figures are for illustrative purposes only and are not intended to identify any specific potential mitigation site. EPA did not consider providing fish passage over a cataract currently blocking anadromous fish access to suitable habitats in tributary stream UT 1.190. Authors propose to increase fish habitat connectivity to increase salmon production potential in a number of ways*. (See pg 22-57 Appendix D, NDM response to EPA revised watershed assessment.)

NDM: ***Removal or Modification of Seasonal Barriers (beaver dams and fish passes).***
Beaver Dams- RESPONSE CSP2 Woody:

1. Authors purport to have documented beaver dams blocking salmon access to upstream habitats in the Pebble project area however review of the PLP EBD shows no empirical studies but a list of purported beaver dam "barriers" in the project area ranging from 0.2 meters to 2 meters high. Bryant (1984) showed that dams of 2 meters in height did not block salmon passage upstream and surveys in the Pebble region have documented salmon above dams higher than 2 meters (Figure 1). Further, authors failed to review the most recent literature by Devries et al. (2012), employed by one of PLPs primary consulting firms on the Pebble Project. They advocate emulating ecosystem engineering by beaver as a less expensive and disruptive fish enhancement technique relative to large-scale in-stream engineering projects. It seems reasonable based on the most recent scientific literature to not manipulate or change current beaver created habitat unless studies show unequivocally that they block fish passage or somehow impair the number of smolts produced per spawner.

Figure 1. Upper Talarik Creek beaver dam sampled 31 Aug. 2008. Coho salmon were documented above this 2 meter high beaver dam and high densities of rearing coho salmon were documented above and below the beaver pond system.

Northern Dynasty consultants neglected to review the most recent scientific literature on the impacts of beaver dams on fishes and fish habitat. For example, Kemp et al. (2012) conducted a systematic meta-analysis of the literature and expert opinion primarily for North America. The most frequently cited benefits of beaver dams were increased habitat heterogeneity, rearing and overwintering habitat and flow refuge for fish, and invertebrate production. Benefits (184) were cited more frequently than costs (119). The majority of 49 North American and European experts considered beaver to have an overall positive impact on fish populations, through their influence on abundance and productivity. The most cited negative effect of beaver activity was that dams impeded fish passage but little research quantifying the existence or magnitude of this impact exists.

The single citation provided by NDM relative to beaver management as a mitigation tool is Finnegan and Marshall (1997) who advocate a variety of engineered structures to prevent beaver from damming culverts, which do not currently exist in the project area, as well as engineered structures to help fish pass upstream of beaver dams. Managing beaver to mitigate for lost fish habitat has questionable efficacy as beaver activity in the Pebble Project area has not been shown to reduce fish production, salmon obviously pass above beaver dams, and recent studies indicate the benefits of beaver dams outweigh the costs. The long-term efficacy of proposed structures are not proven and not documented in the primary literature.

2. **Fish passes or Fishways**: **RESPONSE CSP2 Woody:**
Authors propose to install a fishway on a tributary to Upper Talarik Creek where groundwater from the South Fork Koktuli emerges (pg. 25, Appendix D). As a Biologist on the Tongass for 4 years one of my jobs was to maintain fish passes. Fish passes require constant maintenance, especially after floods and in areas with beaver (who will continually dam the fishway entrance); their effectiveness at passing fish is inconsistent, their effectiveness is rarely monitored and only recently studied and fishways can actually prevent or delay fish passage (Meixler 2009, Lauritzen et al. 2010, Roscoe and Hinch 2010, Hatry et al. 2011, Noonan et al 2011, Bunt et al. 2012, Williams et al. 2012). Performance of fishways varies greatly with their type, design and operating regime, and with the species involved. Of the 50 fish passes installed on the Tongass in Southeast Alaska, none are monitored to determine whether estimated fish production from installation was ever realized. Instead, managing agencies report estimated increases in fish production based on available habitat, which is very different than actually measuring increased fish production.

4. **NDM: Increase the Quality of Existing Off-Channel Habitats***: EPA failed to recognize the potential to improve the quality of existing off-channel habitats by increasing the complexity these areas through the use of boulders, large wood, and deepening or altering the shoreline development ratio in order to create better over wintering habitat and more alcoves, and thus contributing to increased survival.*

RESPONSE CSP2 Woody:

NDM consultants propose to add boulders and large wood, as well as bulldoze new and deeper habitats to increase fish production in watersheds that would be impacted by mining. They also claim that the success of such projects is "settled science". Such a proposal is flawed for a number of reasons. First NDM assumes that habitat is limiting salmon production and that they can somehow improve it. But these rivers already produce the world's largest sockeye and Chinook salmon runs and there is no data to indicate habitat is limiting. But since NDM would eliminate significant amounts of salmon habitat if mining is permitted, they would have to compensate or mitigate for lost habitat. Authors overlook the fact these rivers are wild and although habitats may be disconnected at certain times of the year they are connected at other times. The photographs in attachment D on pages 72 and 73 clearly show how the rivers have moved across the landscape over time. These rivers will continue to move and any mitigation projects to "reconnect" or "improve" habitats will only affect salmon habitat temporarily. Recent science also shows such projects would have to restore 100% of eliminated floodplain and in-channel habitat to detect a fish production increase of 25% with 95% certainty (Roni 2011). The lack of statistically valid pre-mining fish abundance and aquatic biota data in the PLP EBD underscores the fact that they would be unable to show any scientifically valid increases in fish abundance in a before after study of mitigation which is one of the primary problems cited in achieving and evaluating mitigation goals (Quigley and Harper 2006a). A review in SCIENCE (Bernhardt et al. 2005) of US river restoration efforts found that although river restoration has become a highly profitable business with an average of 1 billion spent annually fewer than 10% of 37,099 projects were ever monitored post-construction to determine if objectives were realized. The outcomes of tens of thousands of projects have never been tracked over the long term thus the efficacy of such projects is equivocal. Stewart et al. (2009) found only equivocal evidence of their effectiveness at increasing salmonid abundance and significant variability in success among projects.

5. **NDM: Create New Habitats through the Development of Semi-Natural Channels:** *EPA failed to recognize the potential for development of new off-channel habitats within the three watersheds. These new channels could provide additional spawning and rearing habitats by locating them in locations where subsurface flow will provide the water to the new channel. The authors have personally reviewed and/or visited dozens of potential sites.*

   RESPONSE CSP2 Woody:

   1. Effectiveness of engineered off-channel habitats, primarily for coho salmon, was recently evaluated in British Columbia (Cooperman et al. 2006). Authors indicated that assessment of channel functionality is very limited. A rapid assessment of ten channels showed eight of ten were "functional" but five of the eight had issues that likely compromised their utility to salmon. Although authors assessed three topics 1) physical connectivity, 2) thermal stability and, 3) coho use and growth, they did not show statistically defensible augmentation of coho salmon populations in sites that were purportedly successful. Effectiveness monitoring was listed as needed to determine if off-channels actually augment salmon production.

   2. Morley et al. 2005) compared coho salmon use of constructed versus natural side channels in Washington. Total salmonid densities were not significantly different between channel types, but coho salmon densities were higher in constructed channels and trout densities were higher in natural channels in winter.

   3. Creation of spawning channels for sockeye salmon can result in disease outbreaks and reduced salmon production (Mulcahy et al. 1982)

   4. Price (2012) examined potential effects of spawning channels on Babine Lake sockeye salmon. His review indicated that increasing sockeye salmon stocks artificially using spawning channels can alter prey communities and reduce average weight of juveniles leaving the nursery lake. Marine survival rates declined with increasing numbers of emigrating salmon.

6. **NDM: Increase the Primary Productivity and Productive Capacity for Fish:** *EPA failed to recognize the potential to increase primary productivity and overall productive capacity for fish by developing an appropriate design for their WWTP so that discharges would increase key water chemistry constituents. They also failed to recognize that the entire area has very soft water and thus low productive potential. This situation could be improved through a carefully designed water chemistry enhancement program.*

RESPONSE CSP2 Woody:

1. Changing the water chemistry of area streams fails to recognize basic salmon life history in that salmon imprint on natal stream chemistry (Dittman and Quinn 1996), which enables them to return to and spawn in the streams to which they are adapted. Calcium ions are considered an important odorant that allow sockeye salmon to discriminate their natal stream (Bodznik 1978) a water quality characteristic that NDM proposes to change. Changing stream chemistry could result in salmon not recognizing their natal stream and dying without spawning or they could stray to a stream to which they are not adapted and potentially suffer higher mortality thus lowered productivity.

2. There is no data on area streams and rivers showing that salmon productivity is currently nutrient limited or that nutrients affect the stock recruitment relationship (Adkison 2010).

3. Lake and stream fertilization experiments to increase primary productivity and theoretically salmon populations, assume that nutrients limit salmon production, but this is not always the case:
   - -Wipfli and Baxter (2010) showed that most fish food comes from external or very distant sources, including: from marine systems borne by adult salmon, from fishless headwaters that transport prey to downstream fish, and from riparian vegetation and associated habitats.
   - -Paeliolimnologic studies in Alaska indicate nutrient inputs are not always tied to higher primary productivity or salmon productivity (Chen et al. 2011).
   - -Added nutrients can result in no increased fish growth (Cram et al. 2011).
   - -Nutrient additions can result in nuisance algae blooms or undesireable diatoms (Hyatt et al. 2004)
   - -Nutrient additions can result in declines in primary production due to changes in ecosystem metabolism (Holtgrieve and Schindler 2011).
   - -Nutrient additions did not increase salmonid biomass, growth or retention in 6 California streams (Harvey and Wilzbach 2010).
   - - In some systems the highest yields can be obtained from small nutrient depleted populations (Adkison 2010)

4. Accurate and precise manipulation and control of stream chemistry for the large rivers that would be impacted would be a challenging difficult experiment with unknown outcome.

.

7. NDM claims: "*There is no question about the effectiveness of an appropriate application of these measures to enhance production of aquatic biological resources, especially salmon. Large amounts of money continue to be dedicated towards the implementation of these kinds of measures because they work; this is settled science*." Pg. 67 Appendix D. They also rely heavily on papers by Quigley and Harper (2005, 2006a, 2006b) on Canadian mitigation to support their claims but in actuality these papers actually refute their claims.

   1. Quigley and Harper (2006a) showed that **67% of compensation projects resulted in net losses to fish habitat and only 2% resulted in no net loss.**

2. Quigley and Harper (2006a) showed that 86% of permitted “harmful alteration, disruption of destruction to fish habitat” (HADD) in Canada had larger HADDs and/or smaller compensation areas than authorized.

3. Quigley and Harper (2006a) indicated that habitat compensation in Canada was at best only slowing the rate of fish habitat loss.

4. NDM claims that Quigley and Harper (2006a) conclude compensatory habitat development or enhancement to offset losses “is am excellent conservation strategy, potentially serving as a model for other jurisdictions”, but in fact

5. Quigley and Harper (2006b) **showed that 63% of projects resulted in net losses to aquatic habitat productivity and only 25% achieved no net loss.**

6. Quigley and Harper (2006b) concluded “the ability to replicate ecosystem function is clearly limited”.

Citations

Adkison, M. D. (2010). "Models of the effects of marine-derived nutrients on salmon (Oncorhynchus spp.) population dynamics." Canadian Journal of Fisheries and Aquatic Sciences 67(1): 5-15.

Alamaro, M. 1999. On the feasibility of generating and storing winter ice to meet water demands in the summer. Mechanical Engineer’s Degree Thesis, Massachusetts Institute of Technology. Cambridge MA.

Bernhardt, E.S., et al. 2005. Synthesizing U.S. River Restoration Efforts. Science. 308 (5722): 636-637.

Bodznick, D. 1978. Calcium ion: an odorant for natural water discriminations and the migratory behavior of sockeye salmon. J. Comp. Physiol. 127(2):157-166.

Bryant, M.D. 1984. The role of beaver dams as coho salmon habitat in southeast Alaska streams. In: J.M Walton and D. B. Houston, editors. Proceedings of the Olympic Wild Fish Conference. 23-25 March 1983. Fisheries Technology Program Peninsula College and Olympic National Park. National Park Service. Port Angeles, WA.

Bunt, C. M., T. Castro-Santos, et al. (2012). "PERFORMANCE OF FISH PASSAGE STRUCTURES AT UPSTREAM BARRIERS TO MIGRATION." River Research and Applications 28(4): 457-478.

Clark, I. D. and B. Lauriol. 1997. Aufeis of the Firth River Basin, Northern Yukon, Canada: Insights into permafrost hydrogeology and karst. Arctic and Alpine Research 29(d2): 240-252.

Cooperman, M.S. et al. 2006. Rapid assessment of the effectiveness of engineered off-channel habitats in the southern interior of British Columbia for coho salmon production. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2768. 30 pp.

Cram, J. M., P. M. Kiffney, et al. (2011). "Do fall additions of salmon carcasses benefit food webs in experimental streams?" Hydrobiologia 675(1): 197-209.

Chen, G. J., D. T. Selbie, et al. (2011). "Long-term zooplankton responses to nutrient and consumer subsidies arising from migratory sockeye salmon Oncorhynchus nerka." Oikos 120(9): 1317-1326.

DeVries, P., K. L. Fetherston, et al. 2012. "Emulating Riverine Landscape Controls of Beaver in Stream Restoration." Fisheries 37(6): 246-255.

Dittman, A.H. and T.P. Quinn. 1996. Homing in Pacific salmon: mechanisms and ecological basis. J. Exper. Biol. 199:83-91.

Gustafson et al. 2007. Conserv. Biol. 4: 1009-1020.

Harper, D.J. and J.T. Quigley. 2005. A comparison of the areal extent of fish habitat gains and losses associated with selected compensation projects in Canada. Fisheries. 30(2):18-25.

Harvey, B. C. and M. A. Wilzbach 2010. Carcass Addition Does Not Enhance Juvenile Salmonid Biomass, Growth, or Retention in Six Northwestern California Streams. North American Journal of Fisheries Management 30(6): 1445-1451.

Hatry, C., T. R. Binder, et al. 2011. "Development of a National Fish Passage Database for Canada (CanFishPass): Rationale, Approach, Utility, and Potential Applicability to Other Regions." Canadian Water Resources Journal 36(3): 219-227.

Holtgrieve, G. W. and D. E. Schindler (2011). "Marine-derived nutrients, bioturbation, and ecosystem metabolism: reconsidering the role of salmon in streams." Ecology 92(2): 373-385.

Hyatt, K. D., D. J. McQueen, et al. 2004. Sockeye salmon (*Oncorhynchus nerka*) nursery lake fertilization: Review and summary of results. Environmental Reviews 12(3): 133-162.

Kemp, P. S., T. A. Worthington, et al. 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish. Fish and Fisheries 13(2): 158-181.

Lauritzen, D. V., F. S. Hertel, et al. 2010. "Salmon jumping: behavior, kinematics and optimal conditions, with possible implications for fish passageway design." Bioinspiration & Biomimetics 5(3).

Meixler, M. S., M. B. Bain, et al. 2009. "Predicting barrier passage and habitat suitability for migratory fish species." Ecological Modelling 220(20): 2782-2791.

Mulcahy, D., J. Burke, R. Pascho, and C.K. Jenes. 1982. Pathogenesis of infectious hematopoietic necrosis virus in adult sockeye salmon (Oncorhynchus nerka). Canadian Journal of Fisheries and Aquatic Sciences 39:1144-1149.

Mullner SA, Hubert WA. 1995. Selection of spawning sites by kokanees and evaluation of mitigative spawning channels in the GreenRiver, Wyoming. North American Journal of Fisheries Management 15: 174–184

NMFS. 2013. http://www.nmfs.noaa.gov/pr/species/fish/atlanticsalmon.htm.

Noonan, M. J., J. W. A. Grant, et al. 2012. "A quantitative assessment of fish passage efficiency." Fish and Fisheries.13(4):450-464.

National Research Council. 1996. Upstream: Salmon and society in the Pacific Northwest. National Acadamy Press. Washington D.C.

Price, M. 2012. Potential effects of spawning enhancement on wild Babine sockeye: a review. Prepared for Skeena Wild Conservation Trust. 53 pp.

Quigley, J.T. and D.J. Harper. 2006a. Compliance with Canada's *Fisheries Act*: A field audit of habitat compensation projects. Environ. Mgmt. 37(3):336-350.

Quigley, J.T. and D.J. Harper. 2006b. Effectiveness of fish habitat compensation in Canada in achieving no net loss. Environ. Mgmt. 37(3):351-366.

Roni, P. et al. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific northwest watersheds. No. Amer. J. Fish Mgmt. 22:1-20.

Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management 28:856–890.

Roscoe, D. W. and S. G. Hinch 2010. "Effectiveness monitoring of fish passage facilities: historical trends, geographic patterns and future directions." Fish and Fisheries 11(1): 12-33.

Smith & McCredie 2008, Groundwater Hydrology-Mine; PLP Agency presentations 2008, Anchorage, AK. Available from Pebble Limited Partnership.

Stewart, G.B. et al. 2009. Effectiveness of engineered in-stream structures mitigation measures to increase salmonid abundance: a systematic review. Ecol. Appl. 19(4) 931-941.

Williams, J. G., G. Armstrong, et al. 2012. THINKING LIKE A FISH: A KEY INGREDIENT FOR DEVELOPMENT OF EFFECTIVE FISH PASSAGE FACILITIES AT RIVER OBSTRUCTIONS. River Research and Applications 28(4): 407-417.

Yoshikawa, K., L. D. Hinzman, and D. L. Kane. 2007. Spring and aufeis (icing) hydrology in Brooks Range, Alaska. Journal of Geophysical Research Volume 112.