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Memorandum

To:	Dale Kerner, Gene Bosley (Midas Gold)
From:	Jeff Barrett
Date:	December 20, 2017
File:	19270-003-00
Subject:	Memorandum on Fish Passage Literature in Support of Midas Gold Idaho, Inc. - Stibnite Gold Project, Request for Additional Information (RFAI) 55.

GeoEngineers conducted a review of available scientific literature to identify studies that support the contention that salmonid fish will be successful in passing through the bypass tunnel of the East Fork South Fork Salmon River (EFSFSR) being proposed by Midas Gold Idaho, Inc. (Midas Gold) in their Stibnite Gold Project (SGP) Plan of Restoration and Operations (PRO). We prioritized finding and reviewing studies documenting fish passage through tunnels, and found several papers with applicable examples. However, the literature on tunnels is limited, so we also reviewed studies that show fish passage through long culverts or fish ladders. In addition, a number of studies were reviewed to assess the role of artificial illumination in facilitating or inhibiting fish passage, with an emphasis on studies of salmonid fishes.

The collected literature documents fish passage in a variety of long tunnels, culverts, and fishways, over a wide range of flows, and with variable levels of fish passage improvements. Expected conditions for fish passage through the proposed EFSFSR tunnel fall well within the range of conditions noted in the reviewed studies. We believe this literature review therefore provides a strong basis for concluding fish passage through the tunnel will be successful if appropriate fish passage structures are included in the tunnel design. With respect to the need for illumination, the majority of studies agree that strong contrasts in light levels, such as might be expected at the entrance and exit of the tunnel, inhibit fish passage. Some transitional lighting in these areas could therefore assist in fish entry to the tunnel structures. By contrast, the literature presents variable findings on the need for illumination in long passage structures, so no clear recommendation for the lighting in the main body of the tunnel emerged.

PAPERS DOCUMENTING FISH PASSAGE THROUGH TUNNELS:

A. Rogers, and A. Cane. 1979. Upstream passage of adult salmon through an unlit tunnel. Fisheries Management, vol. 10-2: 87-92.

The authors describe passage of upstream migrating Atlantic salmon through a 1.37-mile-long tunnel between two lakes in North Wales. The tunnel bypasses the entire flow of a river (Afon Nant Peris) around an existing hydroelectric reservoir (Llyn Peris), and is therefore subject to highly variable flows depending upon discharge levels in the river. The upstream end of the tunnel was outfitted with a weir containing electrodes to detect the passing of fish moving out of the tunnel and into the adjacent river. Records of fish passage were therefore accurate as to timing and number of fish, and present a strong demonstration of fish passage through the tunnel.

The tunnel itself is described as being 20.5 feet high and 18 feet wide, with water depths ranging from 10 feet at the downstream end to 5 feet on the upstream end. Although the gradient is nearly flat, the volume of water passing the tunnel produces velocities of 0.4-3.3 feet/second, depending on discharge levels in the river. The tunnel is not lighted and contains bends that prevents light transmission along the length of the tunnel. Fish passage is therefore in complete darkness except near the entrance and exits of the tunnel.

The paper reports results taken during 26 days in October 1978. No fish passed upstream through the fish counting weir on 7 of these days. For the remaining 19 days, fish were recorded passing upstream over the weir, documenting successful passage through the tunnel. Numbers of fish passing upstream over the weir ranged from 1 to 22 fish per day. The authors cite unpublished data to conclude the number of fish passing the weir was "very much of the order which would be expected at this time of the year in this part of the river." If correct, then the tunnel did not impair the normal upstream migration of Atlantic salmon during the duration of the study.

Summary/Applicability: This study clearly demonstrates that anadromous salmonids will swim a considerable distance upstream within tunnels, even in total darkness or when strong flows impede that upstream movement (i.e., up to 3 feet/second).

Gowans, A.R.D., J.D. Armstrong, I.G. Priede, and S. Mckelvey. 2003. Movements of Atlantic salmon migrating upstream through a fish-pass complex in Scotland. Ecology of Freshwater Fish 12: 177-189.

This paper describes a 1.55-mile-long tunnel running between two hydroelectric reservoirs that are part of a complex of such facilities in the River Conon watershed in northern Scotland. The authors captured adult Atlantic salmon migrating upstream to spawn, surgically implanted radio-tags, and then tracked the fish as they moved upstream through a series of fish ladders, Borland fish lifts, and the tunnel. Their overall goal was to document the cumulative effect of these fish passage facilities in limiting the number of fish that passed upstream to headwater streams where they could spawn. Radio-tagged fish initially observed downstream of the tunnel, and later upstream of the tunnel were assumed to have volitionally traveled through the tunnel, a scientifically robust conclusion.

The paper does not describe the tunnel in any detail, except to say it is 10 feet in diameter, and that flows through the tunnel are not regulated, which implies highly variable depths and velocities. Flow usually moves from one reservoir (Loch Meig) to another (Loch Luichart), but flows can reverse when water surface elevations in Luichart are higher than in Meig. Although a gradient is not provided, this reversibility of flows indicates the tunnel has a flat, or nearly flat gradient. The tunnel was not illuminated, so any fish passing through the tunnel did so "in near total darkness."

Of the 54 Atlantic salmon tagged by the researchers a total of 12 entered Lock Luichart after successfully passing a variety of downstream barriers and fish passage structures. Of these 12 salmon, 6 (50%) passed through the tunnel into Loch Meig, and ultimately from there were recorded upstream in potential spawning grounds in the River Meig. A fish that initially passed upstream of the tunnel later was recorded moving back down through Loch Luichart and then passed through the tunnel to Loch Meig. Because their work showed that salmon migration slowed or stopped at night in fish passage structures with turbulent flows (e.g., in the fish ladders), the authors conclude "[p]resumably, the hydraulic conditions in the tunnel were conducive to easy migration."

Summary/Applicability: This second example also demonstrates that anadromous salmonids will swim upstream a considerable distance within tunnels, even in total darkness.

Wollebaek, J., J. Heggenes, and K.H. Roed. 2011. Population connectivity: dam migration mitigations and contemporary site fidelity in arctic char. Evolutionary Biology 11: 207-222.

This paper focused on micro-genetic differences in two populations of Arctic char that were separated when a dam and reservoir were constructed. The authors sought to establish to what extent fish above the dam had differentiated genetically since their separation from the downstream population approximately 20 fish generations into the past (i.e., 64 years). The downstream population was assumed not to have become genetically isolated because of the relative ease of upstream fish moving over or through the dam to the downstream area. The project includes a 0.81-mile tunnel that bypasses the blocking dam, and also spillways at the dam face. The authors speculated that fish might pass upstream through one or the other, providing an opportunity for genetic mixing into the upstream population that would hinder or prevent genetic differentiation. Based on "measured lake levels and estimated velocities" the authors conclude that fish "migration through the tunnel was feasible in less than 3.6% of the year" or 13 days a year. For the spill gates, they estimated fish passage upstream "was possible in less than 1.7% of the year" (6 days/year).

Beyond its length, the authors provide little information on the tunnel. It is reported to have dimensions of 23.3 feet by 23.3 feet, a "neutral gradient" and variable inflows and water surface elevations. The authors concluded passage by Arctic char was only possible when depths were 2 feet or less, which they estimated only occurs for brief periods during the spring. The structure is identified as having been constructed to support the hydroelectric project, rather than as a fish passage device. Presumably it therefore lacked any features to support or enhance fish passage.

The authors found strong evidence that genetic intermingling of the two populations had continued in the upstream population over time, and concluded this intermingling was due to Arctic char travelling through the tunnel and spill gates despite the relative rarity of conditions that would allow such passage. Although no direct observations of fish passage were included in the paper, the authors interpreted their results to "indicate high connectivity [of fish populations] across the dam," and "[s]ubstantial migration among reproductive sites was found." The authors go on to note that such connection existed despite the rarity of conditions permitting fish passage, and despite Arctic char being "low performance swimmers." Based on swimming ability they conclude that "a water velocity of 150 cm/s [4.9 ft/s] is likely an absolute limit for upstream migration for studied char across the dam." Finally, the authors cite a doctoral thesis that used mark-recapture studies (Aass, P. 1973) as corroboration that Arctic char were able to pass upstream past the dam.

Summary/Applicability: Although fish passage in this study was inferred rather than directly observed, the conclusion of fish passage through the tunnel appears robust. Perhaps of most interest is that a poor swimming species (Arctic char) passed upstream even though acceptable depths and current velocities in the tunnel provided adequate passage conditions for only a few days each year. The inference for Midas Gold is that fish passage in their proposed tunnel will occur, even if ideal or even adequate conditions for that passage are rare.

Lupandin, E. 2000. Tuloma River Project – Present salmon migration routes in the Tuloma River System. Report to TACIS. Unpublished report provided by Jaakko Erkinaro, Research Professor of the Natural Resources Institute Finland. +358 405435929. Jaakko.erkinaro@luke.fi.

The Upper Tuloma Dam in Murmansk, Russia was built in the 1960s with a tunnel-fish ladder complex intended to pass Atlantic salmon upstream to the reservoir and river tributaries used for spawning. The tunnel was (and is) used as the tailrace (i.e., carried water exiting the turbines), with discharge from the turbines varying over time depending on flows into the reservoir and targeted production of electricity. Although the tunnel has minimal gradient, it lacked velocity breaks to support fish passage upstream against what were reported to be substantial current velocities generated by discharge from the turbines. Reduced current velocities along the tunnel edges from boundary layer effects presumably supported upstream fish passage. At 183 meters (600 feet) inside of the tunnel a fish ladder entered at right angles to the tunnel alignment. The fish ladder used a series of 30 weirs and associated weir pools to increase the water surface elevation a total of 9 meters (30 feet) over a distance of 260.5 meters (855 feet), with a drop of 0.3 meters (1 foot) at each weir exit. At the end of the fish ladder, there was an 88 meter (288 foot) long resting pool that ended in a Borland fish lift with a 60 meter (196 foot) vertical rise. The fish ladder, resting pool and Borland lift were embedded in the dam structure, and so had no exposure to daylight. Both the tunnel and ladder/resting pool were illuminated. From the base of the dam to the Borland fish lift Atlantic salmon moving upstream had to travel a horizontal distance of 531 meters (1,743 feet, about 0.33 miles).

Small numbers of Atlantic salmon regularly traveled from the lower river up to the Borland fish lift, demonstrating fish passage was feasible with this design. However, the numbers of fish reaching the Borland fish lift were smaller than hoped, and very few fish successfully exited the fish lift into the reservoir. The authors concluded there were two key design problems: 1) the attraction flows exiting the fish ladder into the tunnel were too small, as a proportion of the flow in the tunnel, to successfully attract fish, and 2) the design of the Borland fish lift was flawed (turbulent flows during the filling part of cycle, and poor attraction flows to induce fish to exit the lift and swim into the reservoir). After a few years the fish ladder was converted into a fish hatchery, precluding additional upstream movement of adult salmon.

Summary/Applicability: This study is useful in demonstrating that salmonids will swim a considerable distance within tunnels, even when there is considerable flow opposing that upstream movement (i.e., in the tailrace), or a long series of weir type velocity barriers are in place.

Cambray, J.A. and R.A. Jubb. 2001. Dispersal of Fishes via the Orange-Fish Tunnel, South Africa. Published online in Journal of the Limnological Association of Southern Africa.
http://www.tandfonline.com/doi/pdf/10.1080/03779688.1977.9632929?needAccess=true

The Orange-Fish tunnel is 82.45 km (52.1 mile) long, and links the Orange River to the Great Fish River, in Eastern Cape, South Africa. The study documents that fish traveling through the tunnel can survive the trip, despite the length and potentially fatal hazards (e.g., water quality problems). Fish in the Orange River include common carp, Mozambique tilapia and western mosquitofish (i.e., fish of a wide range of sizes and environmental tolerances). The authors evaluate the potential effects that these surviving fish may have on the indigenous fish fauna of the Great Fish River. [Note, only the abstract was reviewed.]

Summary/Applicability: The study is obviously only tangentially related to Midas Gold's planned tunnel, but does provide evidence that fish can survive extremely long downstream trips in tunnels.

HDR Engineering. 2014. Chehalis River Strategy: Reducing flood damage and enhancing aquatic species-combined dam and fish passage alternatives. Technical Memorandum. http://chehalisbasinstrategy.com/wp-content/uploads/2015/09/Water-Retention-and-Fish-Passage-Report_Final.pdf

The report evaluates a series of potential dam and fish passage alternatives for a flood control structure on the Chehalis River. One option was for a dam that would be used for flood control only. This facility would allow all river flows to pass through 200-foot-long tunnels under the dam during most conditions. When flood control was desired these tunnels would be sealed and river flows not contained by the dam would be diverted into a separate flood diversion outlet. HDR, and its teaming partner, Watershed Science and Engineering, conducted hydraulic modeling to confirm whether such an arrangement of tunnels could maintain target passage velocities for coho and Chinook salmon of 2 feet/second or less. Their modeling confirmed that a series of 9 tunnels, 9 feet by 12 feet in dimension, with staggered conduit invert elevations and roughened surfaces would meet the target fish passage velocity. HDR concluded the design was likely to pass fish upstream at flows up to 2,000 cfs.

Planning and design work on this project is continuing, so the proposed fish passage tunnels have not yet been constructed.

PAPERS DOCUMENTING FISH PASSAGE THROUGH LONG CULVERTS, AND FISHWAYS:

Lang, M., M. Love, W. Trush. 2004. Improving Stream Crossings for Fish Passage – Final Report. Humboldt State University Foundation for National Marine Fisheries Service (NMFS) Contract No. 50ABNF800082

This study examined upstream migration by salmonids in several culverts on the Northern California coast, and analyzed what flows juveniles and adults selected. The study found that adult fish generally did not migrate during either low flows or peak flows. Migration levels were highest as peak flows began declining (i.e., descending limb of hydrograph). Only 2 percent of observed adult attempts to swim upstream in culverts occurred at flows that were less than the 27% annual exceedance flow (i.e., discharge was higher than this level only 27% of the time), and one third of all passage attempts occurred between the 2.5% and 1% annual exceedance flow. By contrast, upstream passage by juvenile fish occurred over a wide range of flows, with most passage occurring at discharges of 40% to 2.5% annual exceedance flow. One of the culverts they examined was 9.8 ft by 10 feet by 400 feet long, made of concrete, and with notched concrete weirs 2 feet in height and spaced every 25 feet. The slope was 2.2%. This is effectively a small tunnel with a similar fish passage design to one of the alternatives being considered by Midas Gold. Coho and Chinook salmon and steelhead pass readily through this structure.

This study was in coastal watersheds with short migration distances. Thus, the migration timing and selected flow levels by salmon and steelhead likely reflect, in large part, volitional preferences. By contrast, Chinook salmon and steelhead arriving at the proposed EFSFSR tunnel must travel a considerable distance upstream, and are therefore subject to a range of possible conditions (e.g. flow and temperature) along this migration pathway. Thus, the timing of arrival and flows selected for passage within the EFSFSR will likely be due to both migration conditions and volitional preference.

Summary/Applicability: This study documents a strong preference by Chinook salmon and steelhead for upstream movement during high discharge levels. This suggests Midas Gold may want to prioritize design of fish passage in the tunnel for higher discharge levels, fish arrival timing (potentially delayed by downstream conditions) is favorable. The study may also validate the weir and pool passage structure design being considered for the tunnel.

Cooke, S., K. Smokorowksi. 2015. CanFishPass: Inventory of Canadian Fish Passage Facilities. Cooke Lab at Carleton University. http://www.fecpl.ca/projects/canfishpass-inventory-of-canadian-fish-passage-facilities/

CanFishPass is a database of fish passage facilities in Canada. The database has too few entries for it to be a comprehensive inventory, and it therefore likely a work in progress. A sort of the database using the field "Length of fishway" identified the pool and weir fish ladder at Boulevard Lake Dam in Ontario, Canada. This fishway is 211 meters (692 feet), and successfully passes steelhead. A web review indicates the ladder is a weir and pool design up the face of the dam, as well as pools blasted in bedrock in the river approach to the dam. At Whitehorse Dam, in Yukon Territory, Canada, a 366-meter (1,200 foot) weir and orifice fish ladder successfully transports adult Chinook salmon above the dam into Schwatka Lake. The vertical distance covered by the ladder is 15 meters (49 feet), which is a nearly flat gradient (0.04%).

Summary/Applicability: The relevance of this example is that these are long-distance fishways that successfully pass Chinook salmon and steelhead trout. They also use designs, weir-pool and bedrock pools (similar to Midas Gold's proposed muck bays) being considered for the tunnel.

Bartlett, J. E. 2005. Adult salmon and steelhead counts at the North Fork Fish Ladder, 2004 and 2005. Internal report: Portland General Electric.
https://www.fws.gov/pacific/fisheries/hatcheryreview/Reports/columbiagorge/EC--029NForkAdultFishLadderCounts-JBartlett04_05.pdf

At 1.9 miles, it is reported to be one of the longest existing fish ladders in existence. Design specifications were not found, but photographs of the ladder indicates it is naturally lighted, and uses a low gradient weir-pool design. It effectively passes hundreds of Chinook and coho salmon and steelhead trout. Fish are passed in both spring/summer and fall months. This same complex of hydroelectric projects includes two fish bypass facilities for juvenile salmonids traveling downstream. One is a 1.5-mile bypass that carries fish from a surface collector in the reservoir downstream before dumping them in the North Fork Fish Ladder. As juveniles pass down the ladder then enter a counting facility. The counted juveniles are then passed through a 5.1 mile long bypass pipe that carries them downstream to a release point in the Clackamas River.

Summary/Applicability: This example represents a very long fishway that successfully passes adult Chinook salmon and steelhead. Also, the facilities demonstrate that downstream migrating smolts and juveniles can successfully pass through miles of bypasses and pipes. Both support the contention that the Midas Gold tunnel will be successful in fish passage.

U.S. Army Corps of Engineers (USACE). 2017. Web-based fact sheets for John Day Dam and Ice Harbor Dam and their fish passage facilities. http://www.nwp.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/492594/john-day-lock-and-dam/ and http://www.nww.usace.army.mil/Locations/District-Locks-and-Dams/Ice-Harbor-Lock-and-Dam/

In common with most dams on the Columbia River system, John Day and Ice Harbor have fish ladders. A quick review suggested that these two have the longest ladders of the USACE-managed facilities, and also have large vertical rises. The John Day has two fish ladders, each 24 feet wide, 1,080 feet long, and rising vertically 105 feet (slope of 9.7%). Ice Harbor's fish ladder is 16 feet wide, 661 feet long, and rises 101.5 feet (slope of 15.4%). Both facilities use a weir and orifice design with 6-foot-long overflow crests and an 18-inch square orifice on each side of the fish ladder. Velocities are controlled to be within 1.5 to 4 feet per second at both facilities. Both facilities are run-of-the-river, so pool heights, and therefore flow into the fish ladders, are relatively constant.

Summary/Applicability: These fish ladders are of interest because of their length, and relatively steep slope. Both pass thousands of salmon and steelhead yearly, as documented by extensive monitoring. So they clearly establish that salmonids will swim considerable distances within confined channels, at slopes that would not be passable except for the idealized engineering of the ladders (i.e., if natural would be too steep). Analogs to the EFSFSR tunnel are obvious.

PAPERS ON LIGHTING FOR FISH PASSAGE:

NMFS Northwest Region. 2011. Anadromous salmonid passage facility design.
http://www.westcoast.fisheries.noaa.gov/publications/hydropower/fish_passage_design_criteria.pdf

This is a very detailed design guidance document for fish passage facilities. The McMillen Jacobs tunnel design team is aware of it and has used it to specify certain design guidance criteria for fish passage in the EFSFSR tunnel. The document is divided into sections covering different aspects of fish design structures. Lighting requirements and recommendations are located in several sections:

- Under the section on transport channels (section 4.4): “Ambient lighting should be provided in all transport channels, if possible. Otherwise, acceptable artificial lighting must be used.” Also, “Designs must avoid…lighting transitions.”
- Under the section on fish ladders (section 4.5.3.8). “Ambient lighting is preferred throughout the fishway, and in all cases abrupt lighting changes must be avoided.”
- In section 4.9.1.2 under Miscellaneous Considerations: “Natural lighting should be consistently provided throughout the fishway. Where this is not possible (such as in tunnels), artificial lighting should be provided in the blue-green spectral range. Lighting must be designed to operate under all environmental conditions at the installation.”
- In section 7.7.1.3 containing criteria for culverts and road crossings: “Natural or artificial supplemental lighting should be considered in new or replacement culverts that are over 150 feet in length. Where supplemental lighting is required, the spacing between light sources should not exceed 75 feet. Available research results indicate that different species of anadromous salmonids respond differently to lighting conditions (COE 1976), and NMFS engineering staff should be specifically contacted if a culvert greater than 150 feet in length is under consideration.”

Collectively, these criteria strongly suggest, but do not require, lighting in fish passage structures that are long enough to be dark without artificial light. The exception, a requirement for lighting in transport channels, applies only to short lengths of channel that transport fish between different sections of fish passage facilities (e.g., from one segment of fish ladders to another segment). Interestingly, the specific lighting recommendations change from avoiding abrupt changes, to blue-green spectral range, to consulting with NMFS.

Summary/Applicability: A reasonable inference from this guidance is that NMFS will likely want Midas Gold to install lighting in the tunnel, but the types, intensity, and frequency of that lighting will likely be determined based on site-specific factors. Interestingly, the COE 1976 citation is not included in the list of references, so it was not possible to review it.

NMFS Northwest Region. 2008. Anadromous salmonid passage facility design.
http://www.habitat.noaa.gov/pdf/salmon_passage_facility_design.pdf

This is an older version of NOAA's facility design guidance, covered here to show the consistency of lighting recommendations over the recent past. The language is identical to that in the 2011 document.

- Under the section on fish ladders (section 4.5). "Ambient lighting is preferred throughout the fishway, and in all cases abrupt lighting changes must be avoided."
- In section 4.9 under Miscellaneous Considerations: "Natural lighting should be consistently provided throughout the fishway. Where this is not possible (such as in tunnels), artificial lighting should be provided in the blue-green spectral range. Lighting must be designed to operate under all environmental conditions at the installation."
- In section 7.7.1.3 containing criteria for culverts and road crossings: "Natural or artificial supplemental lighting should be considered in new or replacement culverts that are over 150 feet in length. Where supplemental lighting is required, the spacing between light sources should not exceed 75 feet. Available research results indicate that different species of anadromous salmonids respond differently to lighting conditions (COE 1976), and NMFS engineering staff should be specifically contacted if a culvert greater than 150 feet in length is under consideration."

Summary/Applicability: NOAA's guidance to provide artificial lighting when natural lighting is not available has not changed since the 2008 document was published.

NMFS Southwest Region. 2001. Guidelines for salmonid passage at stream crossings.
http://www.westcoast.fisheries.noaa.gov/publications/hydropower/fish_passage_at_stream_crossings_guidance.pdf

Although from the Southwest Region, this document pre-dates the Northwest Region guidance discussed above. The single discussion on lighting: "Natural or artificial supplemental lighting should be provided in new and replacement culverts that are over 150 feet in length. Where supplemental lighting is required the spacing between light sources shall not exceed 75 feet."

Summary/Applicability: The key value of this document is to show how much NMFS thinking on lighting changed between 2001 and 2008. The multiple discussions of lighting in 2008 could simply reflect the greater diversity of fish passage structures in that document, but probably also reflect a growing sense that lighting is important for fish passage.

USDOT/FHA. 2007. Design for fish passage at roadway-stream crossings: synthesis report. USDOT publication No. FHWA-HIF-07-033.

The document examines lighting for long culverts which can become partially or totally dark in their interiors. Research noting behavioral differences in light vs. dark passage of fish species (Welton et al. 2002; Kemp et al. 2006; Stuart 1962), and that conclude darkness may dissuade certain fish from entering a structure (Weaver et al. 1976) are cited. Avoidance of darkness is not considered proven, but the guidelines recommend that lighting be considered when installations require long structures. The document cites the 2001 NMFS Southwest Region report reviewed above for possible design recommendations.

Summary/Applicability: Additional information that contributes to considerations for tunnel lighting.

Boubee, J., I. Jowett, S. Nichols, E. Williams. 1999. Fish passage at culverts, a review, with possible solutions for New Zealand indigenous species. NIWA, Dept. of Conservation, Wellington, New Zealand.

The authors conclude the effect of light on fish migration remains an area of debate. It includes a review of some scientific references: Kay and Lewis (1970) found that in four culverts between 183 and 229 meters long, darkness seemed to have little effect on fish passage. Dane (1978a) reports that some studies have found passage times to be higher in darkened flumes compared to illuminated flumes, with the opposite occurring in fishways. Mallen-Cooper et al. (1995) found that daylight had a strong effect on the upstream movements of fish. The Boubee study notes that fish use both visual and tactile (e.g. lateral line senses) clues for orientation and movement. Non-turbulent flow in some flumes and culverts may therefore reduce a fish's ability to detect and interpret currents in the dark, causing them to move more hesitantly. In fishways, fish may be better at sensing the usually strong currents such that lighting is less important. Considering all the literature they reviewed the authors conclude that lighting of culverts is not necessary, but that long culverts should be straight to allow light to pass along the length of the culvert.

Summary/Applicability: This study may be relevant given Midas Gold tunnel fish passage would involve strong, turbulent flows for most of the alternatives being considered. However, the Gowans et al. (2003) study reviewed above came to the opposite conclusion; that turbulent flows impede fish movement in darkness. Although this study probably does not represent support for having no illumination at all, it does suggest lights don't need to be so frequent or intense that they prevent shadows or darker areas within the tunnel.

Slatick, E. 1970. Passage of adult salmon and trout through pipes. Special Scientific Report—Fisheries, 592:1-18. US Fish and Wildlife Service, Washington DC.

A series of experiments in pipes of different diameters and lengths, with and without lighting, and using adults of a variety of salmon species and steelhead. Goals were to determine: (1) if adult salmon and trout at Bonneville Dam on the Columbia River would use a pipe as a passageway and (2) how the conditions at the entrance and within the pipe, diameter, length, illumination, and flow would influence passage. He found that Chinook (fall and summer stocks), sockeye and coho salmon, and steelhead trout passed through unilluminated pipes up to 82.3 meters long. Fall Chinook, sockeye, coho and steelhead all traveled through the pipes more quickly when they were illuminated, but this effect was only statistically significant for fall Chinook and steelhead. Summer Chinook showed a non-significant delay in passage in illuminated pipes, which the author could not explain. Separate tests did not indicate that sharply contrasting light levels impeded fish passage (i.e., brightly lit entrance pools versus dark interiors of the pipes).

Summary/Applicability: This study was reviewed primarily due to its repeated reference in other studies. The differing results for Chinook (fall vs. summer) is somewhat troubling, as the stock that will use the EFSFSR tunnel is a spring/summer stock. This example is superseded by more recent work, and it is notable that more recent studies have documented the inhibitory effects of sharply contrasting light levels.

Bell, M. 1990. Fisheries handbook of engineering requirements and biological criteria. USACE North Pacific Division.
https://www.fs.fed.us/biology/nsaec/fishxing/fplibrary/Bell_1991_Fisheries_handbook_of_engineering_requirements_and.pdf

This handbook contains a variety of observations and recommendations with respect to fish reaction to lights:

- Fish may avoid light intensity changes, both high and low, as they do when seeking shadow areas during fishway passage (page 18.1).
- Fish will respond to shadow and light patterns, generally favoring cover. In clear water, downstream migrants usually move in darkness periods, but under turbid conditions they will move in daylight (page 18.1).
- In clear, still water Coho salmon were attracted to sub-surface lights with extremely low intensities (in the range of .000025 to .0035 foot-candles) whereas at an intensity of 1.3 foot-candles, no attraction occurred. In both clear and turbid waters, surface lights with an intensity of 0.015 foot-candles proved to be an effective guiding stimulus (attraction), while a ten-foot-candle light was effective in stopping fish, and a 300 watt light (approximately 5,800 foot-candles) repulsed fish. [Note the author lists “full moonlight” as having an intensity of 0.2 foot-candles, and “full daylight” an intensity of 10,000 foot-candles].
- Colored lights had no significant effect on fish passage (page 24.1).
- Light, when used artificially as a guidance stimulus, repels fish at higher intensities and attracts them at the lower intensities. Under natural conditions, fish react to moonlight, perhaps explaining the response to low levels of artificial light.

Summary/Applicability: This source provides information on light intensity that can attract fish into a darkened fishway, but the intensities selected are so low that they may not be relevant to Midas Gold. For tunnel passage, lighting would be designed to reduce the contrast between ambient light levels at the entrance of the tunnel, and the tunnel itself. Very low light intensities in the tunnel may make sense on dark nights, but would be unlikely to have any effect during daylight hours when ambient light levels would be much higher.

Larinier, M. 2002. Biological factors to be taken into account in the design of fishways, the concept of obstructions to upstream migration. Bulletin French Peche Piscic. 364 suppl., pages 28-38

https://www.kmae-journal.org/articles/kmae/pdf/2002/04/kmae2002364s28.pdf

Lighting considerations in fish migrations and fish passage facilities are reviewed as part of a larger examination of fish passage. The author reviewed a number of publications, many of them older (pre-1995), and used them to make conclusions about the importance of light for fish passage:

- The author cites several studies (including the Rogers and Cane study reviewed above) to show that fish will travel long distances in tunnels, culverts, and pipes without illumination.
- Bell (1986) is cited to show that the progress of migrating fish is not slowed down by darkness. Similarly, Long (1959) is cited for his observation that migrating steelhead trout delayed longer before entering a darkened fishpass, but once they had done so they passed more quickly than when the same pass was lit (two versus eight minutes per pool in the fishpass).
- Columbia River dam studies were also cited. At the Dalles Dam less than 10% of the migrators used the pass between 20.00 hrs and 04.00 hrs, irrespective of whether or not the pass was lit. At the McNary Dam, the trials showed that the fish did not enter the pass at night, no matter what the lighting conditions. In

contrast, the light allowed the fish which did enter the pass before nightfall to complete their passage (Fields, 1966).

- Observations at Grand Sault hydroelectric facility on the Madeleine River, Quebec showed that Atlantic salmon did not enter the underground section of a pool pass when the transition from light to darkness was sudden. The pass did not function correctly unless it was lit.
- The author concludes that it would appear preferable, if a pass has to be covered or buried, to avoid any sudden transition between the intensity of outside light and that inside the pass or pipe, through some form of lighting in the first section (artificial light, windows, widening the entrance).

Summary/Applicability: This study includes a substantial review of older literature that might not be familiar to present-day practitioners. It seems clear that lighting is not essential to providing for fish passage, of salmonids at least. However, whether artificial lighting aids or impairs fish passage seems to depend on the particular study or situation. The conclusion that strong light gradients impede fish movements corroborates that of other studies, and the NOAA design guidance. Therefore, lighting in the beginning portions of the tunnel is likely required, with enough intensity to mimic ambient daylight. Such lighting could then presumably transition over a distance to some lower light level that extends through the remainder of the tunnel.