Columbia River Project Water Use Plan

Kinbasket Reservoir Fish And Wildlife Information Plan

Kinbasket Reservoir Rainbow Trout Life History and Habitat Use Assessment

Implementation Year 3

Reference: CLBMON-7

Kinbasket Reservoir Rainbow Trout Life History and Habitat Use Assessment (Year 3)

Study Period: September 2016 – August 2017

Ktunaxa Nation Council
7825 Mission Rd, Cranbrook, BC, V1C 7E5

January 5, 2018

WLR Monitoring Study No. CLBMON-07

Kinbasket Reservoir Rainbow Trout Life History and Habitat Use Assessment (Year 3)

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Cover Photo:

Tributary survey in Tsar Creek in May 2017. Photos in this document © Katrina Caley and Misun Kang, CCRIFC.

Suggested citation:

Warnock, W.G., and K. A. Caley. 2018. WLR Monitoring Study No. CLBMON-07 (Year 3) Kinbasket Reservoir Rainbow Trout Life History and Habitat Use Assessment. Prepared for BC Hydro by the Ktunaxa Nation Council. Cranbrook, B.C.

EXECUTIVE SUMMARY

Rainbow Trout (*Oncorhynchus mykiss*) were historically distributed throughout the Columbia and Canoe Rivers, and historic Kinbasket Lake, which were impounded by the construction of the Mica Dam in 1973. Mica Dam created Kinbasket Reservoir, a 216 km long, 43,200 ha ultraoligotrophic water body. This is a technical report that summarizes the findings of Year 3 (2017) of a multi-year monitoring study of the life history, habitat use, and potential operational impacts of the Mica Dam on the spawning ecology of Rainbow Trout in Kinbasket Reservoir.

Kinbasket Reservoir has a normal annual operating range of approximately 25 m, and during periods below full pool, a large shoreline drawdown zone is exposed. Typical reservoir drawdown occurs during the winter months, beginning in January, reaching low pool level by approximately the end of April. The timing of low pool level coincides with the general timing of Rainbow Trout migration to tributaries to spawn. Rainbow Trout have specific spawning habitat requirements in tributaries, preferring a range of stream gradients, depths, and velocities, in addition to gravel substrate and a thermal regime suitable for spawning and embryo development. Locations of Rainbow Trout spawning are currently unknown in tributaries to Kinbasket Reservoir. If suitable spawning habitat is present in the portion of tributaries that traverse the drawdown zone or migration barriers are exposed in these portions during the spawning migration, dam operations may potentially impact the success of Rainbow Trout spawning or subsequent embryo incubation.

Year 3 of this study continued to use a combination of biotelemetry and habitat surveys to determine biological characteristics and movement of Rainbow Trout during the suspected prespawn and spawning time period, as well as the habitat characteristics of potential spawning streams through the portions that traverse the drawdown zone. Snorkel surveys were conducted through the spring in the drawdown zone of Succour Creek, a stream with high potential to support spawning of Rainbow Trout.

Seventeen fish have been tagged in previous years of study. Fixed acoustic receivers revealed large scale movement patterns of 11 of 17 tagged Rainbow Trout throughout the course of the study from September 2014 to May 2017. Fish detected by acoustic receivers had a variety of home range size and location preferences. Pre-spawn and/or post-spawn movements to and from home ranges appeared to occur in four tagged fish in late March-late April, and late May-mid June, respectively. Several fish migrated to the upstream end of the Columbia Reach of the reservoir during these forays.

Tributaries with the potential to support Rainbow Trout spawning were identified from literature review, and the drawdown zone of four of these streams was surveyed during low pool in early May 2017. Three of these streams were revisited from their initial surveys in 2015 to extend the survey lower within the drawdown zone. Surveys extended from the top of the drawdown zone at the high pool mark (754 m) to the reservoir at ~729 m. Two tributaries (Windfall and Tsar Creeks) had suspected or complete fish migration barriers that were exposed within the drawdown zone. Within the drawdown zone, all four of the tributaries had suitable substrate and gradients shallow enough to support Rainbow Trout spawning, but these were confined to small, lower reaches within the drawdown zone. Analysis of water temperature data from Succour Creek indicate the creek was thermally suitable in the drawdown zone for spawning in 2015 and 2016 between April and June, and reservoir operations have the

potential to inundate suitable spawning habitat throughout this period and prior to earliest times of modeled fry emergence. Despite the apparent suitability of the drawdown zone for Rainbow Trout spawning in Succour Creek, snorkel surveys have not found evidence of spawning (redds) or the presence of mature fish in any year surveyed.

Management Question	**Hypotheses**	**Status**
What are some basic biological characteristics of Rainbow Trout populations in Kinbasket Reservoir (e.g., distribution, abundance, growth and age structure)?		Two Rainbow Trout morphs may be present in Kinbasket Reservoir – a smaller insectivorous morph and a larger piscivorous morph. Large-bodied fish vulnerable to the capture method may be less abundant than in comparable large lakes. Rainbow Trout are distributed throughout the reservoir; this question will be addressed more thoroughly in Year 4 when more data is available.
Does operation of Kinbasket Reservoir result in blockage or reduced success of upstream migration of Rainbow Trout spawners in tributary streams?	H1: The productivity of Rainbow Trout populations is limited by habitat impacts directly related to operation of Kinbasket Reservoir. H1A: Operation of the reservoir restricts upstream passage of Rainbow Trout spawners to reservoir tributaries due to low water elevations.	Eleven tributaries have been surveyed throughout the course of this study thus far to elevations ~729-731m. Barriers that may restrict or completely exclude migratory Rainbow Trout have been identified within the drawdown zone of seven of these tributaries; however, it is unknown whether any of these tributaries contain runs of adfluvial Rainbow Trout. Further habitat surveys at lower reservoir elevations and on unsurveyed tributaries will be addressed in Year 4.
Does operation of Kinbasket Reservoir cause the flooding of	H1B: Operation of the reservoir reduces Rainbow Trout egg and	Habitat surveys in six of 11 tributaries surveyed throughout

Rainbow Trout spawning habitat within the drawdown zone and lower sections of tributaries, causing adverse effects on egg and fry survival?	fry survival due to inundation of spawning habitats within the drawdown zone.	the study program thus far revealed reaches of possible suitable spawning substrate and habitat characteristics in the drawdown zone. Amongst these six tributaries, the vast majority of suitable habitat is found in Succour Creek. Analysis suggests that reservoir operations inundated potentially suitable spawning habitat in Succour Creek during the thermally suitable time for spawning and embryo incubation and prior to earliest modeled fry emergence timing in 2015 and 2016, but the severity of predicted impact differed between these years. Despite the apparent suitability of habitat, no Rainbow Trout spawning activity or redds were observed during snorkel surveys in any year of study. Further habitat and redd surveys, as well as a more detailed analysis of temperature data, to be addressed in Year 4.
Can modifications be made to the operation of Kinbasket Reservoir to protect or enhance spawning success of these Rainbow Trout populations?		To be addressed in Year 4.

ACKNOWLEDGEMENTS

We thank Bill Green, Karen Bray, Guy Martel, and Gerry Oliver for review and discussion of methodology and safety programs for this project.

Jim Clarricoates, JoAnne Fisher, Kenton Andreashuk, Jaime Cristales, Misun Kang, Heather McMahon and Dominique Nicholas provided technical field, logistics and administrative support for this project. José Galdamez provided support for mapping. Angela Prince and Scott Cope of Westslope Fisheries Ltd provided useful background information and advice on project methodology and Kinbasket Rainbow Trout capture and telemetry.

Jamie Tippe provided guiding services for Rainbow Trout capture and use of his boat. We thank him for his expert knowledge in boat operation and fish capture from years of experience on the Kinbasket Reservoir.

Last but not least, thank you to Jason Watson and Trish Joyce at BC Hydro for management of this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Background

Kinbasket Reservoir was created by the construction of Mica Dam in 1973, under the terms of the Columbia River Treaty. The purposes of the creation of this earthfill, high head dam and reservoir were for optimized, coordinated power generation between Columbia River mainstem dams in the US and Canada and for downstream flood control. The reservoir inundated 216 km of the length of the Columbia River between Mica and Donald, and is among the largest reservoirs in British Columbia, with a maximum surface area of 43,200 ha. Prior to dam construction, the majority of this habitat was free flowing, with the exception of a lacustrine portion known as Kinbasket Lake that was 13 km long and had a surface area of 2,250 ha (Prince 2001a). The reservoir can be coarsely segregated into two main reaches, with the Columbia and Canoe reaches meeting at the historic confluence of the Canoe and Columbia rivers, where the Columbia River turns southward (approximately where Mica Dam is currently situated). The reaches of the reservoir are typically bounded by steep valleys and are narrow, with stretches becoming riverine at low pool. Three large lacustrine portions of the reservoir occur: at the confluence of the Canoe and Columbia Reaches, at the historic location of Kinbasket Lake near the confluence with the Sullivan River, and at the confluence with the Bush River. Stream inputs are largely glacial, draining the high elevation northern tips of the Selkirk and Monashee mountains from the West, and the extensively glaciated West slopes of the Canadian Rockies from the East.

Operations of Mica dam result in extreme annual fluctuations of the reservoir levels. Kinbasket Reservoir elevations may vary between a maximum of 754.38 m and a minimum 707.41 m, and may occasionally be brought up to a maximum elevation of 754.68 m on application to the Comptroller of Water Rights if there is a high probability of spill (BC Hydro 2007). Drawdown from full pool normally begins slowly in September, and draft rate increases through the winter, with a levelling off of drafting and normal low pool occurring in late April. During the spring, discharge from Mica dam decreases, which coincides with the normal spring freshet, which rapidly refills the reservoir through the spring and early summer.

Interior populations of Rainbow Trout (*Oncorhynchus mykiss*) spawn in the spring in streams, during periods of rising water temperatures consistently exceeding 6-8 °C and the ascending limb of the hydrograph (McPhail 2007)(Figure 1) Spawn timing for inland populations may occur in April-July, and mostly depending on hydrographic characteristics of the spawning stream, the latitude and elevation. Spawning is followed by egg incubation in gravels before emerging as fry. This process typically lasts 1-2 months depending on incubation temperature (McPhail 2007). Rainbow Trout spawning and incubation timing thus coincides with the period that Kinbasket Reservoir is refilling from low pool elevation.

This can result in two potential alternatives in which reservoir operations can limit Rainbow Trout recruitment, and thus productivity. Firstly, the pre-spawning migration period into critical spawning habitat may be obstructed by in-stream migration barriers exposed during the coinciding low pool elevations of the reservoir. Secondly, Rainbow Trout may spawn in the drawdown zone of streams immediately upstream from their confluence with the reservoir in low pool periods. These habitats may be inundated in some years of reservoir operation when reservoir elevations do not reach typical low pool, or fill rapidly or early, or else they may be inundated subsequent to spawning. Inundation of gravels where embryos are incubating changes the nature of the incubation environment; Rainbow Trout require flowing water to constantly provide developing embryos with oxygen and to remove metabolic waste products. In addition, emergence of fry directly into an open water lentic habitat may increase predation and reduce foraging opportunities. This study is designed to detect whether Rainbow Trout are susceptible to these potential limitations on recruitment success in the years of study, as these uncertainties have been identified by the Water Use Plan Consultative Committee (BC Hydro 2007).

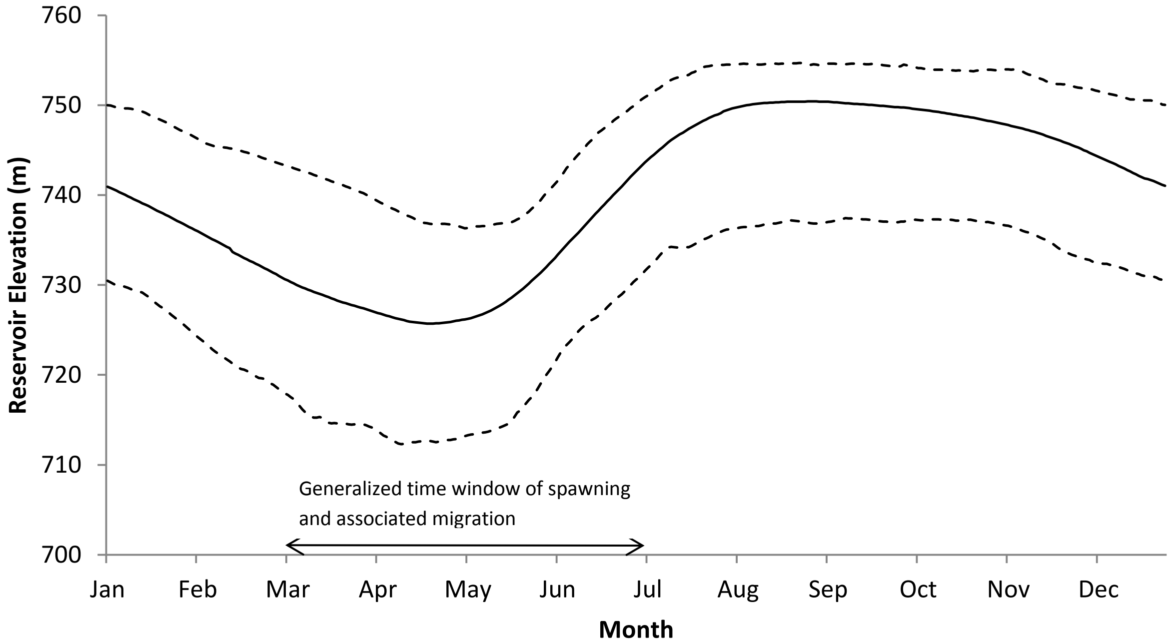


Figure 1: Generalized life history timing of Rainbow Trout compared with the mean (solid line) and minimum and maximum (dashed lines) reservoir elevations in the Kinbasket Reservoir, 1976-2015.

Rainbow Trout – life history and biological characteristics in Kinbasket Reservoir

Kinbasket Reservoir holds a modestly popular, but productive fishery for Rainbow Trout (Pole 1995, Bray 2002). The origin of indigenous Rainbow Trout in Kinbasket Reservoir is from Redband Columbia River trout that were locally adapted to the upper Columbia River complex from Arrow Lakes, upstream to Columbia Lake. The indigenous strain included a large piscivorous form, colloquially referred to as yellowfin trout, which was largely adfluvial from the Arrow Lakes, and spawned in the Canoe River and its tributaries (Peterson and Withler 1965, Prince 2001b). Post-reservoir phenotypic and genetic surveys indicate that current strains appear to be a cross between indigenous forms and introduced hatchery origin, which source from the Lardeau River, a tributary to Kootenay Lake (“Gerrard” strain) (Fidler 1994, Taylor 2000).

A large amount of habitat was inundated for Columbia River Rainbow Trout upstream from Mica Dam, resulting in a shift of valley bottom habitat from primarily riverine to lacustrine. The life history form that now inhabits the reservoir is adfluvial. Spawning and rearing habitat may be limited in tributaries to the reservoir, as most of these provide poor habitat for Rainbow Trout spawning and rearing, or have suitable sections that are seasonally inundated (Fielden et al. 1992, Oliver 2001). Based on the similar but slightly higher elevation and latitude of Kinbasket Reservoir, spawn timing for adfluvial Rainbow Trout may mirror that or be slightly later than Arrow Lakes Reservoir. Spawning and associated migration occurs in Arrow Lake populations between April and June (inclusive), with peak migration and spawn timing of the final week in May (Toth and Tsumura 1996, Drieschner et al. 2008). Emergence periods follow, from mid-June to early September, although most fry outmigrate shortly after emergence in late June to early August (Drieschner et al. 2008, Hawes and Drieschner 2013). Although many fish emigrate as fry, juveniles may rear within the stream for an additional time period, as they do in tributaries to Arrow Lakes Reservoir (Decker and Hagen 2007).

Few tributaries in Kinbasket Reservoir are likely to support resident Rainbow Trout populations or a large spawning population of adfluvial forms above the full pool mark, due to physical habitat characteristics that are limiting for this species. Limiting habitat characteristics include: low productivity and cold water temperatures due to glacial origin, high stream gradients or barriers above the drawdown zone and large freshet discharges that interfere with optimal flow stability that are conducive to Rainbow Trout spawning ecology (Fielden et al. 1992, Fausch et al. 2001, Oliver 2001, Golder 2003). Of direct tributaries to the reservoir that are possibly impacted by drawdown, Succour Creek has consistently been identified by prior research as having the highest abundance and densities of Rainbow Trout (Fielden et al. 1992, Oliver 2001). This stream was theorized to have greater Rainbow Trout abundance due to its lower gradient, stable flows, non-glacial origin (low turbidity and warmer temperatures) and suitable rearing habitat. Rainbow Trout have also been observed occupying the drawdown zone in the spring, during the generalized regional spawn timing window for the species. In addition, Camp Creek near Valemount may have historically been, and may continue to be an important Rainbow Trout spawning stream, particularly for indigenous Columbia River yellowfin Rainbow Trout (Peterson and Withler 1965, Fidler 1994, Prince 2001b). This tributary does not flow directly into the Kinbasket Reservoir, but flows into the Canoe River shortly above its confluence with the reservoir. Other various tributaries support low densities of Rainbow Trout and thus may support adfluvial spawning and juvenile rearing. The drawdown zone has been theorized to possibly support Rainbow Trout spawning for the tributary portions that traverses this shoreline, but this has not been confirmed by any study (Fielden et al. 1992; Oliver 2001). Arndt (2009) speculates that adfluvial Rainbow Trout from Kinbasket Reservoir may migrate into tributaries to the Columbia River upstream from the reservoir, rather than tributaries directly feeding into the reservoir, due to more favourable spawning habitat.

Management Questions

The management questions (MQs) associated with this monitoring program are (BC Hydro 2007):

1) What are some of the basic biological characteristics of Rainbow Trout in Kinbasket Reservoir?
2) Does operation of Kinbasket Reservoir result in blockage or reduced success of upstream migration of Rainbow Trout spawners in tributary streams?

3) Does operation of Kinbasket Reservoir cause the flooding of Rainbow Trout spawning habitat within the drawdown zone and lower sections of tributaries, causing adverse effects on egg and fry survival?
4) Can modifications be made to the operation of Kinbasket Reservoir to protect or enhance these Rainbow Trout populations?

The monitoring program will provide a quantitative baseline dataset to establish basic biological characteristics of the Rainbow Trout in Kinbasket Reservoir. It will provide information on habitat use, life history and rough estimates of abundance, and possible factors affecting Rainbow Trout productivity.

Management Hypotheses

The primary aim of this monitoring program is to provide baseline information on Rainbow Trout in Kinbasket Reservoir to better inform the relationship between reservoir operations and recruitment. It is designed to specifically test the following hypotheses using assumptions of spring (April-June) habitat use being linked to spawning activity:

H_1: The productivity of Rainbow Trout populations is limited by habitat impacts directly related to operation of Kinbasket Reservoir.

H_{1A}: Operation of the reservoir restricts upstream passage of Rainbow Trout spawners to reservoir tributaries due to low water elevations.

H_{1B}: Operation of the reservoir reduces Rainbow Trout egg and fry survival due to inundation of spawning habitats within the drawdown zone.

Key Water Use Decision Affected

Implementation of the proposed monitoring program will provide information to support more informed decision making with respect to the need to balance storage in Kinbasket Reservoir with impacts on fish populations in the reservoir. Specifically, it will provide the information that is required to support future decisions around maintaining the current operating regime or modifying operations to protect reservoir Rainbow Trout populations.

METHODS

Overview, study objectives and limitations

The general approach of this study partially draws upon the design of a previous Water Use Planning tributary fish migration access assessment, CLBMON-32A (Drieschner et al. 2008, Hawes et al. 2010, 2011, 2012, 2013, 2014) and refines it to apply to Kinbasket Reservoir with additional biotelemetry data collected on the population of Rainbow Trout.

The study is designed to answer the management questions (MQs), as outlined in the previous section. The main limiting factor of study on the Kinbasket Reservoir is the size of the system (Figure 2). In addition, the remoteness of the reservoir requires extensive travel with limited safe access and contact points. Given these safety and logistical constraints, sampling effort to capture fish for biotelemetry is biased to focus on central and southern portions of the reservoir.

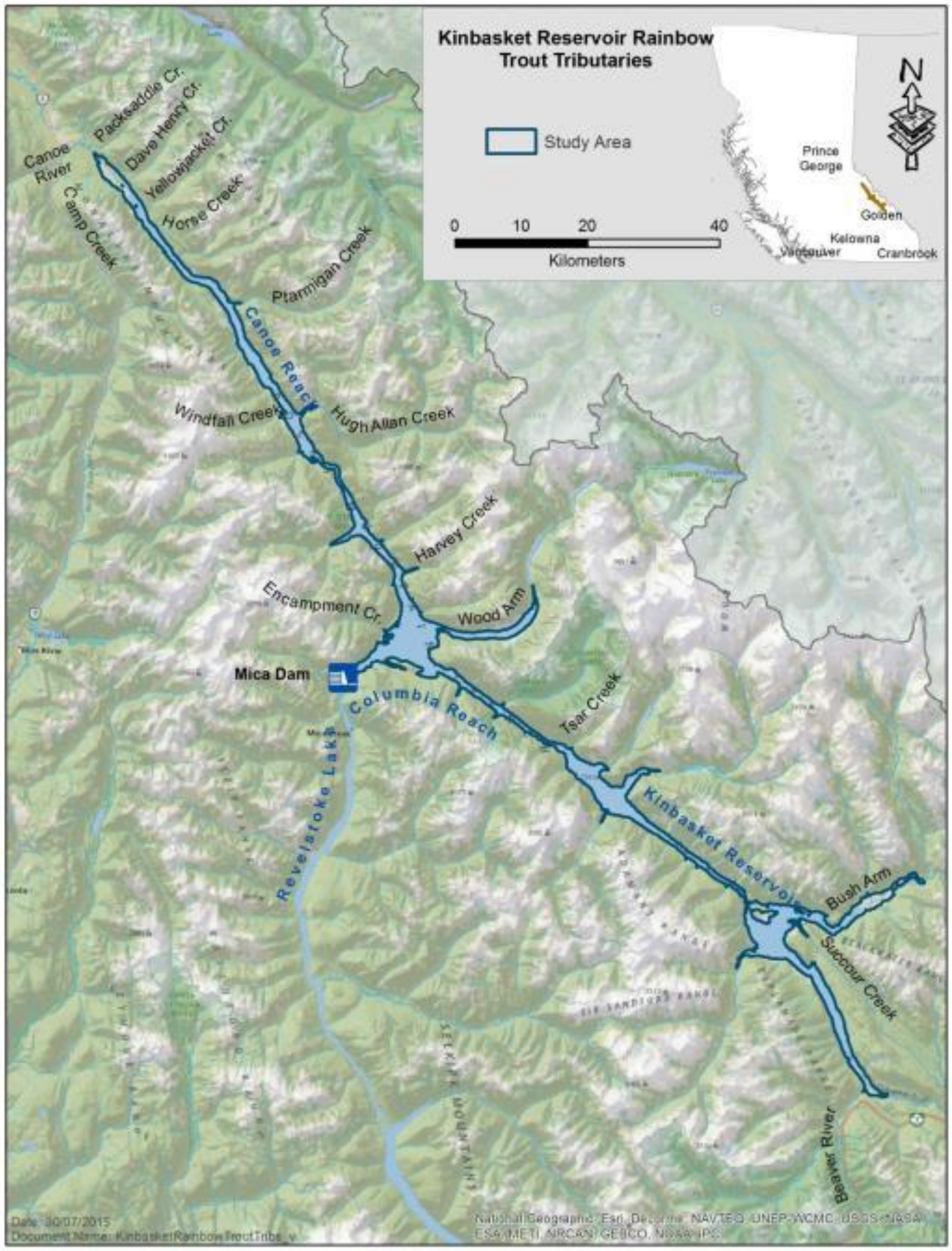


Figure 2: Locations of study area and tributaries in the Kinbasket Reservoir

Tributary surveys are conducted in the drawdown zone during the low pool period in the spring, to determine if: a) there are any migratory barriers exposed during low pool, and b) if there is suitable habitat available for Rainbow Trout spawning, or presence of Rainbow Trout spawning. Selected tributaries (Figure 2) were chosen based on prior research which indicated possible Rainbow Trout spawning habitat (Oliver 2001) and observations of the presence of the species (FIDQ 2014); however, the study design is limited to sampling small tributaries. The operational effects on larger tributaries (e.g., Canoe River, Columbia River, Bush River) cannot be assessed by this study design.

Rainbow Trout capture and tagging

Capture and tagging of Rainbow Trout was not conducted in Year 3 of the study; however, since tags transmit for more than a year, fish that were tagged in Years 1 and 2 of the study were tracked by fixed receivers in Year 3. 17 Rainbow Trout were implanted with combined acoustic-radio tags (CART) between both first two years of study. See Caley and Warnock (2017) for details on capture and tagging methodology.

Fixed receiver tracking

This study is designed to detect year-round habitat use of Rainbow Trout and aspects of their migratory life history (e.g., adfluvial movements; MQ1), as well as tributary use during the pre-spawn and spawning season (MQs 2 and 3). Originally mobile radio tracking CART tags from fixed-wing aircraft was to be used to detect movements during the spawning season (Caley and Warnock 2016); however, due to low numbers of tagged Rainbow Trout, mobile radio tracking from fixed-wing aircraft was removed from the study. Opportunistic ground tracking and fixed acoustic receiver tracking was not conducted in Year 3, due to the small likelihood of detection. The CART transmitters use a coded radio (codes 111-160) frequency of 150.210 MHz for individual tag identification and an acoustic transmission of 76 KHz. The radio burst rate is 4.5 or 5.0 seconds continuous and acoustic pulses are transmitted every 60.5 s (CART16) or 100.5s (CART11).

As part of the CLBMON-05 Kinbasket Reservoir Burbot Life History and Habitat Use Assessment (Warnock et al. 2014, Kang et al. 2015), multiple fixed acoustic receivers were deployed in the study area in June 2014, July 2015 and May 2016 (Figure 3). Four of the receivers deployed in 2016 were replacements for the 2015 receivers that could not be retrieved due to loss or malfunction. A total of 26 receivers were actively tracking during Year 3 of the CLBMON-07 study. See reports of CLBMON-05[1] for more information on receiver set timings and active tracking periods. Receiver locations were selected such that constrictions in the valley were “gated” to track movement amongst areas (Gutowsky et al. 2013). Fish were considered to use a “home range” by reviewing the quantity and duration of detections in a specific reservoir area (Figure 3). Where the majority of detections occurred over a sustained period of several months, within one or more large reservoir areas, this was considered the home range for the tagged fish. Fish were assessed as making potential pre or post-spawn movements if they appeared to make a directed movement from or back to a preferred home range during the months of March, April,

[1] https://www.bchydro.com/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/kinbasket-fish-wildlife.html

May or June, which coincides with the generalized timing window for pre and post-spawn movements in Rainbow Trout. To be interpreted as a possible pre-spawning migration, the fish must have migrated past two successive receivers, away from its home range, and remained undetected returning to its home range throughout the spawning season or until it was detected making a post-spawn migration. Post-spawning migrations were inferred if the fish returned past the same successive receivers in a directed movement after a period of being absent for at least 7 days.

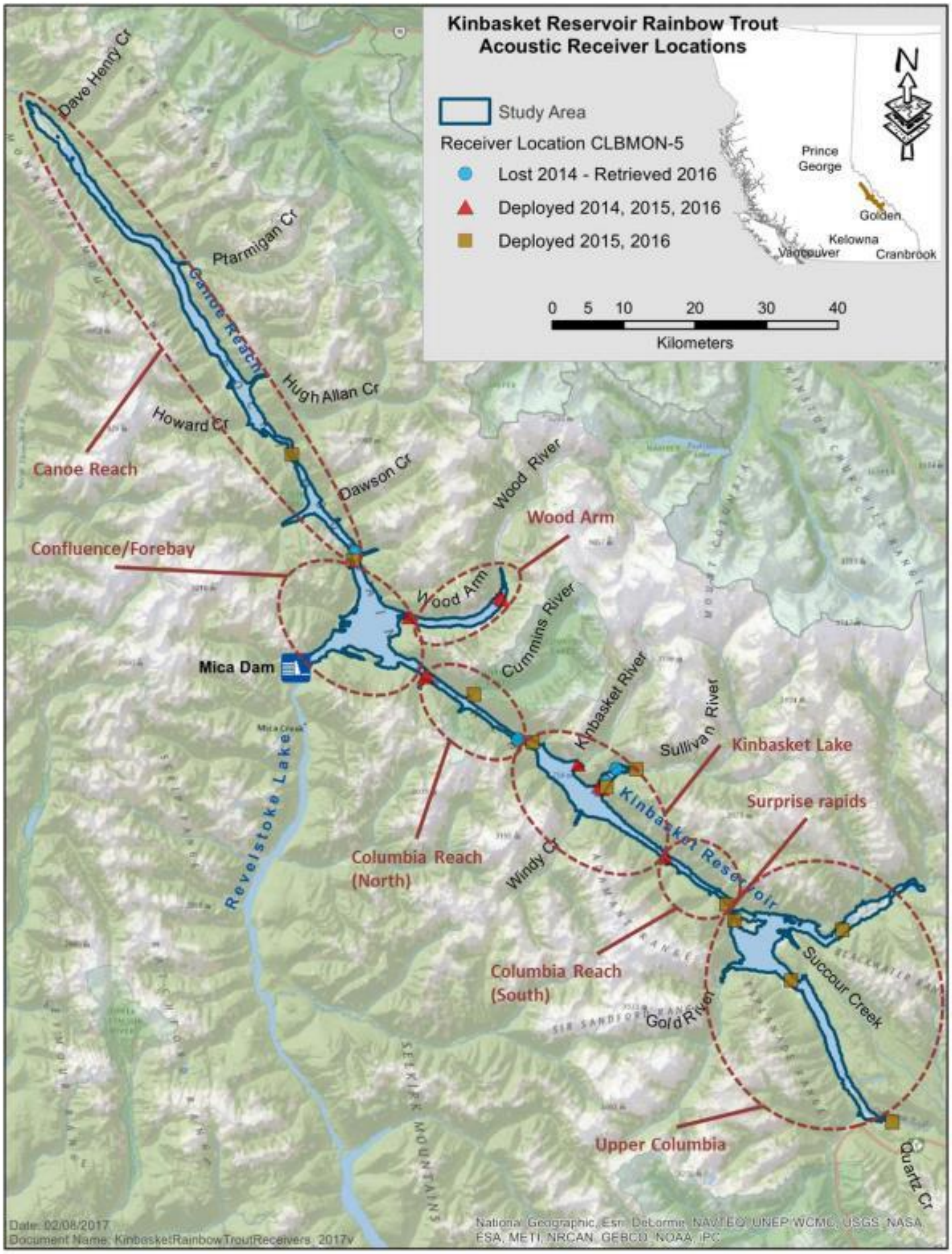


Figure 3: Locations of 26 acoustic receivers within Kinbasket Reservoir, and general areas of reservoir sampling for Rainbow Trout and describing home ranges.

Tributary access, stream habitat and thermal suitability

Detailed surveys and habitat assessments of selected tributaries were completed between May 2nd and May 3rd, 2017. The purpose of the surveys was to: i) identify potential barriers to upstream movement of adult Rainbow Trout; and ii) record stream habitat characteristics to identify potential Rainbow Trout spawning habitat.

These surveys built on those that were completed in Year 1 (2015; Caley and Warnock 2016). Reservoir elevation dropped to between 728.76 m and 728.96 m during the 2017 survey period, which was approximately 10 m lower than during a similar time period in 2015. It was therefore possible to extend the surveys further down the drawdown zone on Harvey, Hugh Allan and Windfall Creeks. In addition, one new stream was surveyed, Tsar Creek. A summary of the tributary surveys completed in 2017 is provided in Table 1. A map showing tributary locations is provided in (Figure 3).

Stream elevation was measured using a Sokkia GRX2 RTK-accurate GPS at the boundaries of consistently measured reaches along the full length of the stream beginning at the top of the drawdown zone (~754 m). Typical elevation accuracy using this equipment is +/- 30 cm. The length of each reach depended on the total horizontal length of stream through the drawdown zone; we estimated reach length in order to provide a total number of over 15 measured transects so that stream habitat would be adequately characterized. Horizontal reach length was determined on-site using an angle compensating digital rangefinder. Any barriers encountered were also surveyed. Elevation was recorded at the top and bottom of the barrier so that length and height could be calculated. The type of barrier (i.e., woody debris, boulders) was also noted. Elevations obtained from the Sokkia were verified by taking daily reference measurements at the reservoir level and comparing them to known reservoir levels provided by BC Hydro. Any differences between the recorded and known reservoir elevations were used to correct stream elevation measurements.

Stream habitat characteristics were recorded at a transect perpendicular to the stream taken at each reach boundary using methods similar to Oliver (2001). Parameters measured included: gradient, water depth, wetted and bankfull widths, water velocity, dominant and sub-dominant bed material, cover type, and habitat unit type. Gradient was calculated as a % slope based on the total measured horizontal length of the drawdown zone and total elevation lost from the top to bottom of the drawdown zone, Stream width was measured with a survey tape, and depth was measured by averaging three meter stick measurements across the transect. The Velocity-Head Rod method was also used to roughly determine velocity at each of the depth measurement locations by observing the degree of deflection of water on the meter stick (Carufel 1980). Substrate, cover type and habitat unit type were determined by visual inspection along each reach. Substrate was classified according to Wentworth scale particle classifications, and potential spawning gravels were considered if they were in the 4-64 mm size range. The linear distance of suitable spawning gravel outcroppings was noted wherever they were encountered, unless they occurred in a small patch that could not support a single Rainbow Trout redd (<0.2 m^2; Bjornn and Reiser 1991).

Table 1: Summary of tributary surveys conducted in 2015 - 2017

Tributary	Lowest Elevation Surveyed (m)	Tributary Survey	Temperature Logger	To be completed in 2018
Packsaddle Creek	n/a		X	X
Dave Henry Creek	731.19[a]	X	X	
Yellowjacket Creek	731.41	X	X	
Horse Creek	731.14	X	X	
Ptarmigan Creek	731.8	X	X	
Hugh Allan Creek	728.93	X X		
Windfall Creek	728.98	X X	X	
Harvey Creek	728.94	X X	X	
Encampment Creek	n/a		X	X
Tsar Creek	728.96	X	X	
Unnamed tributary north of Gold River	738.26	X	X	
Beaver River	734.47[a]	X		
Succour Creek	730.41	X X X	X X X	

[a] Survey captured the full extent of the drawdown zone, as these tributaries flow into the Canoe or Columbia Rivers at the lowest elevation surveyed

X = 2015 field activities, X = 2016 field activities, X = 2017 field activities

A temperature logger (Hobo Pendant® Data Logger) was installed at the top of the drawdown zone of each surveyed tributary. Each logger was placed in a housing unit constructed of PVC pipe which was secured to a 1 m length of t-post. The t-post was used to anchor the housed logger which was buried at the approximate depth that Rainbow Trout redds are excavated (15-30 cm; see Irvine et al. 2013).

Rainbow Trout initiate spawning when mean daily water temperatures exceed 6 ^{o}C, optimal incubation temperatures occur between 7 and 10 ^{o}C, and acute mortality for developing embryos is encountered at 16 ^{o}C (McCullough et al. 2001, Muhlfeld 2002, Carter 2008). We thus used lower and upper thresholds of 6 and 16 ^{o}C to determine if and when the thermally suitable time period occurred for spawning and incubation. Where water temperature was available, we modeled fry emergence assuming a regionally developed threshold of 480 accumulated thermal units for incubation (Irvine et al. 2013). Emergence dates were then compared to reservoir elevations to determine the severity of reservoir inundation over suitable habitat for Rainbow Trout spawning within the stream. In Succour Creek, the severity of impact was determined by plotting the cumulative inundation of potentially suitable spawning substrate exposed during the thermally suitable spawning and incubation time period.

Biological observations were made in streams during habitat surveys, and presence of any fish or redds were noted as they were encountered.

Snorkel surveys

Snorkel surveys were conducted in the spring in 2017 to assess the presence and abundance of Rainbow Trout during the spawning period and presence of redds. Snorkel surveys started at the top of the drawdown zone and progressed downstream until the reservoir was reached. Fish species and numbers observed during the survey, as well as the presence of redds were recorded. Succour Creek was selected for snorkel surveys, as it has the highest potential to support Rainbow Trout spawning (Caley and Warnock 2016, Oliver 2001). The stream originates from a lake, and unlike most snowmelt dominated or glacial fed stream in the region, stream clarity remains high throughout the spring freshet period. Habitat surveys in Year 1 of the study indicated potential for the drawdown zone portion of Succour Creek to provide extensive spawning habitat for Rainbow Trout (Caley and Warnock 2016). Snorkel surveys were selected as the most appropriate method to monitor Succour Creek for Rainbow Trout spawning activity as they cause minimal disturbance to the habitat and fish, are low cost, and have modest equipment requirements, which is ideal for remote locations (O'Neal 2007).

A crew of two people was used to complete the surveys. One person snorkeled while the other person supervised the survey from the stream bank. The supervising crew member recorded data and ensured that any potential hazards were mitigated for (e.g., woody debris, wildlife).

RESULTS

Fixed receiver tracking

Eleven of 17 implanted tags were detected by acoustic receivers during the course of this program. Seven of these fish were detected in Year 3 of the study. Movement patterns of Rainbow Trout tagged in this program are described in Appendix A.1 for the entire period of tracking data available. Greater detail is given to describe movements during periods of presumed pre-spawning or spawning periods (March to June). Reservoir areas and detection locations can be visually cross referenced with descriptions by consulting Figure 3.

Nine of the 11 fish tracked by fixed receivers provided data during the presumed pre-spawning and spawning period, and four of these appeared to make directed movements that were interpreted as possible pre or post-spawn migrations. Of the fish that made possible spawning forays, all four appeared to make directed movements upstream from the Columbia Reach and into the Upper Columbia area, and two of these four appeared to head towards the confluence of the Columbia River with the reservoir, at the upstream end of the Upper Columbia area (Figure 3). The timing of these movements was between late March and late April. All of these fish returned to their home ranges by late May – Mid-June. See Appendix A.2 for maps showing the locations of acoustic receivers that detected each tagged fish. All physical characteristics recorded at the time of capture are summarized in Caley and Warnock 2016 and 2017.

Tributary access, stream habitat and thermal suitability

A total of four tributaries were surveyed during the spring 2017 program in early May, coinciding with the minimum reservoir level elevation. A summary of key tributary measurements and observations is provided in Table 2. Photographs of surveyed tributaries are shown in Appendix B.1. Longitudinal elevation profiles for each surveyed stream can be found in Appendix B.2.

With respect to barrier surveys, three new barriers were encountered. Windfall Creek had four barriers identified in the 2015 survey, and in the 2017 survey, had an additional barrier identified at 732 m elevation. This barrier is composed of LWD and boulders, is 1.5 m in height, and is a potential fish migration barrier (APPENDIX B.1. – Tributary photographs, Figure 12). Tsar Creek had two barriers identified, one 2.5 m in height, occurring within the drawdown zone at 738 m elevation, and another 1.7 m in height occurring at 735 m elevation. (APPENDIX B.2. – Stream elevation profiles through drawdown zone, Figure 13). The first barrier (2.5 m height) appears to be a complete migration barrier and the second is a potential barrier, as there is an alternate bank which fish may be able to ascend.

Water clarity was generally high for most of the tributaries, so visual surveys to collect opportunistic biological data were possible. Fish presence in the drawdown zone was not observed in any streams. Gravel substrate in the size range suitable for Rainbow Trout spawning was found in all streams surveyed, but not in great quantities. Gravels of the size class possibly suitable for Rainbow Trout spawning tended to be distributed at the lower end of the surveyed area of the drawdown zone, as the gradient of most tributaries became shallow as they approached the reservoir elevation (~729 m) (See APPENDIX B.1. – Tributary photographs, Photograph 2, Photograph 4, Photograph 6, Photograph 8, and APPENDIX B.2. – Stream elevation profiles through drawdown zone).

Temperature data was unavailable for revisited tributaries (Harvey, Hugh Allan, Windfall Creeks), as temperature data loggers were missing from 2015 deployment and not retrieved. Temperature data was available for Succour Creek, as the loggers were retrieved during the spring 2017 snorkel survey, and temperature data for the previous year (2016) was compared to reservoir elevations to determine the potential impact of reservoir operations on potentially suitable spawning habitat in the drawdown zone. Retrieval of additional loggers also allowed retrospective analysis of impacts that would have been present in 2015 during the full potential spawn timing (see analysis in Caley and Warnock 2017).

In 2015, temperatures were suitable for spawning and embryo incubation starting on April 22, 2015, and continued during a period of rapid reservoir refilling until upper embryo incubation temperatures were exceeded on June 26, 2015 (Figure 4A). The earliest possible date of fry emergence was extrapolated to occur on June 7, 2015. The potential impact of reservoir operations on potentially suitable spawning substrate was severe in 2015, as 38% of suitable substrate patches were inundated by the earliest possible date of emergence, and 81% of suitable habitat was inundated by the last possible date of emergence (Figure 4B).

In 2016, temperatures were suitable for spawning and embryo incubation starting on April 16, 2016, and continued during a period of rapid reservoir refilling until upper embryo incubation temperatures were exceeded on June 7, 2016 (Figure 5A). The earliest possible date of fry emergence was extrapolated to occur on May 31, 2016. The potential impact of reservoir operations on potentially suitable spawning substrate was less severe in 2016 than 2015, as 12% of suitable substrate patches were inundated by the earliest possible date of emergence, and 33% of suitable habitat was inundated by the last possible date of emergence (Figure 5B).

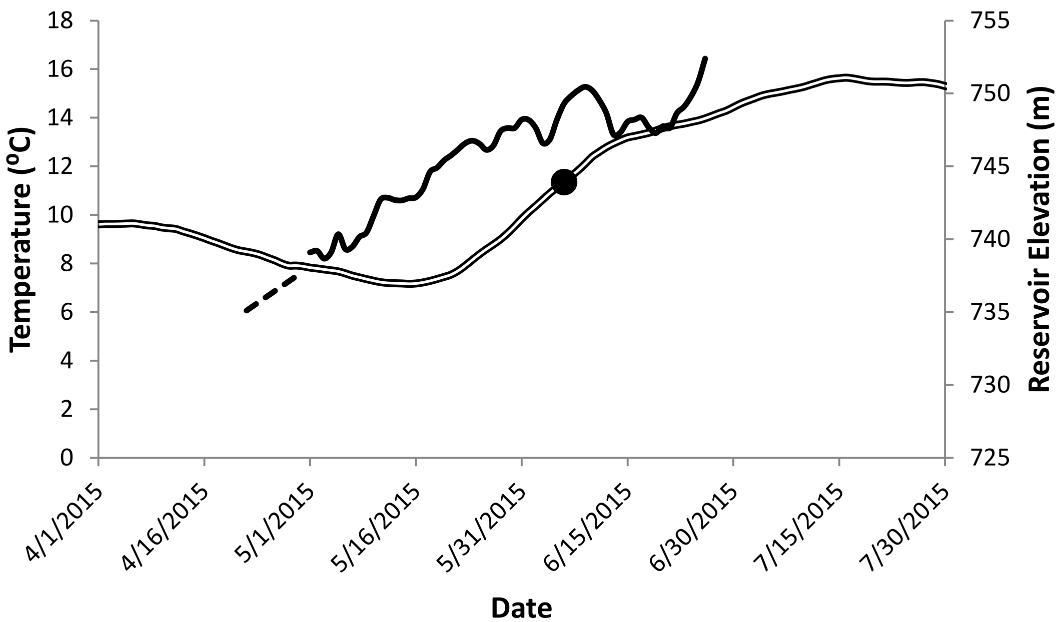
Table 2: Summary of key tributary measurements and observations during the 2017 surveys

Parameter	Harvey Creek[a]	Hugh Allan Creek[a]	Windfall Creek[a]	Tsar Creek
Survey Date(s)	April 25, 2015 & May 3, 2017	April 26, 2015 & May 2, 2017	April 27, 2015 & May 2, 2017	03-May-17
Reservoir Elevation (m)	728.78	728.93	728.93	728.78
Length of DDZ Surveyed (m)	780	1020	600	280
No. of Reaches	37	52	32	14
Reach Length (m)	20	20	20	20
Channel Type	Plane Bed	Plane Bed	Step pool	Cascade
Mean Depth (cm)	32	n/a[b]	31	29
Mean Bankfull Width (m)	94.7	111.5	77.1	168.2
Mean Wetted Width (m)	9.8	19.2	8.8	6.4
Gradient (%)	3.2	2.5	4.3	8.0
Mean Velocity (m/s)	1.0	n/a[b]	0.80	1.8
Dominant Substrate	Gravel	Boulder	Cobble	Cobble
Spawning Gravels (m)	155	100	120	10
Fish Present	None observed	None observed	None observed	None observed
Redds Observed	None observed	None observed	None observed	None observed
Fish detected during opportunistic radio tracking?	No[c]	No[c]	No[c]	n/a[c]
Barriers / Type	None	None	5 (coarse woody debris, boulders)	2 (coarse woody debris)

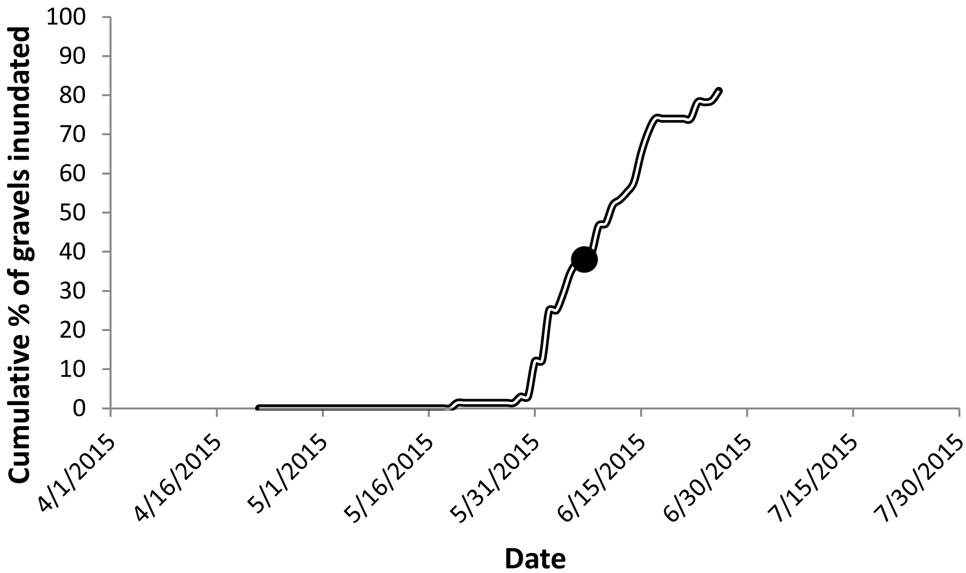
[a] Values presented reflect information collected from 2015 and 2017 surveys

[b] Stream was too deep and swift to wade

[c] Opportunistic radio tracking not completed in 2017 due to expiry of active tags and low likelihood of detection

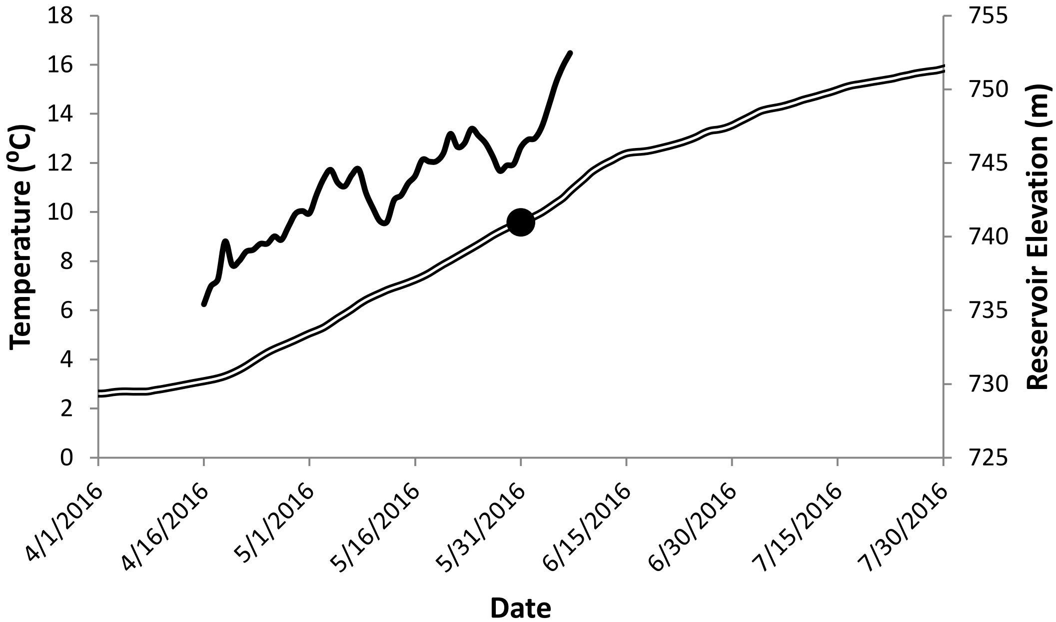


A)

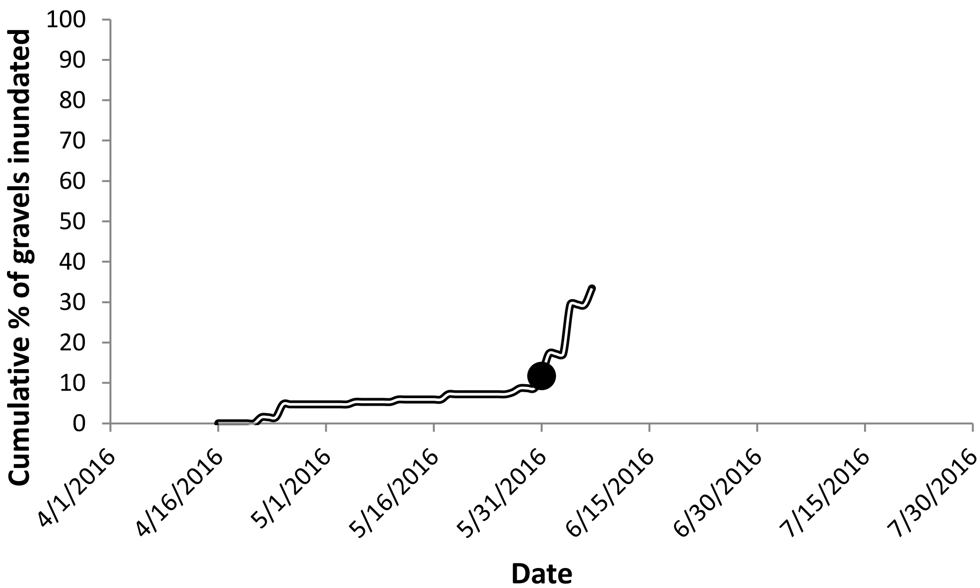


B)

Figure 4 A) Daily mean water temperature of Succour Creek during the period in which water temperatures were suitable for spawning and embryo incubation and spring/summer reservoir elevations (double solid line) in 2015. The dotted line is modeled temperatures, and the solid line into which it merges is measured temperatures. B) Cumulative percent of potentially suitable spawning substrate exposed in the drawdown zone of Succour Creek that became inundated with reservoir refilling during the period in which water temperatures were suitable for spawning and embryo incubation in 2015. The circle in both figures A and B represents the earliest date of emergence modeled from the accumulated thermal units of the initial spawn date



A)



B)

Figure 5 A) Daily mean water temperature of Succour Creek (solid line) during the period in which water temperatures were suitable for spawning and embryo incubation and spring/summer reservoir elevations (double solid line) in 2016. The circle represents the earliest date of emergence modeled from the accumulated thermal units of the initial spawn date. B) Cumulative percent of potentially suitable spawning substrate exposed in the drawdown zone of Succour Creek that became inundated with reservoir refilling during the period in which water temperatures were suitable for spawning and embryo incubation in 2016. The circle in both Figures A and B represents the earliest date of emergence modeled from the accumulated thermal units of the initial spawn date

Snorkel surveys

Only one snorkel survey on Succour Creek was conducted on June 15th, 2017, as site access issues prevented monthly surveys in April and May. A summary of fish counts for all surveys is provided in Table 3. Counts and size classes of rainbow trout observed in the 2017 survey were similar to the 2016 survey, and the majority of the observed fish were approximately 0-10 cm in length and thus immature (Figure 6). Large numbers of Mountain Whitefish and Largescale Suckers (Figure 7) were also observed during the June survey, which resembled results of the 2016 May survey. In terms of diversity, seven species were encountered in 2017 (Table 3). No redds were observed during the survey.

Figure 6: Juvenile Rainbow Trout observed in Succour Creek

Figure 7: Largescale suckers observed in Succour Creek during the May 18th, 2016 snorkel survey

Table 3: Summary of snorkel survey observations in Succour Creek on June 15, 2017

	Counts (size bins in cm)						
Species	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm	Total Count
Rainbow trout	38	4	3				45
Mountain Whitefish	89	22					111
Brook Trout	2	3	1				6
Largescale Sucker			273	318	2		593
Redside Shiner	1						1
Northern Pikeminnow				3	3	1	7
Sculpins	1						1

DISCUSSION and RECOMMENDATIONS

Fixed receiver tracking

Similar to the results from Years 1 and 2 of this study, a limited number of fish were available for tracking, thus inferences are based on a small sample size (Caley and Warnock 2016).
Generally, the majority of detections for most of the summer, fall or overwintering periods were between the outlet of Canoe Reach and the Sullivan Bay entrance. Rainbow Trout 157 had the greatest coverage of the reservoir, traveling between the outlet of Canoe Reach to Esplanade Bay at the southeast end of Kinbasket Lake. Large-scale movements of Rainbow Trout have been documented in other large systems where seasonal movements are made to access suitable habitat for feeding, overwintering or spawning (Ford et al. 1995, Andrusak and Thorley 2013). Rainbow Trout 116 traveled the least of the tagged fish, with detections only at the entrance of Sullivan Bay. Thus, Rainbow Trout likely have great variety in home range size in Kinbasket Reservoir, with individuals ranging from relatively resident to their capture location to highly mobile (Harrison et al. 2014).

Some limited information is available from this program for tagged Rainbow Trout movements during the spawning and spawning migration season. In Year 2 of the study, five of the tagged fish were interpreted as undertaking directed movements (Caley and Warnock 2017). With additional data from another year of tracking during the post-spawn period, one of these fish (Rainbow Trout 115) is no longer suspected to have undertaken a directed movement. Four fish were thus inferred to make directed spawning movements throughout the course of this study. All four of these fish made both pre-spawn movements and post-spawn movements, and Rainbow Trout 117 repeated the same pre-spawn movement timing and direction in 2017 that it had undertaken in 2016. Pre-spawn movements generally occurred between late March and late April, and post-spawn return movement generally occurred between late May and mid-June (Figure 8).

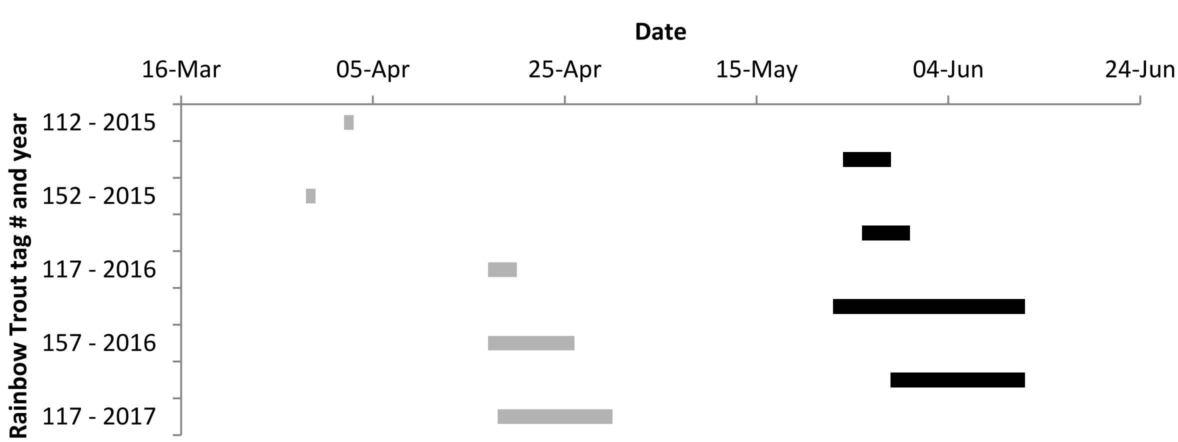


Figure 8: Pre (gray bars) and post (black bars) spawning migration timing interpreted from acoustic receiver detections of tagged fish during the generalized spawning period for Rainbow Trout. Pre-spawn bar width is the time period between the detection date of the fish leaving its home range and the last detection at subsequent upstream receivers within the reservoir. Post-spawn bar width is the time

period that elapsed for the fish to make the return journey it made during the pre-spawn period. Post-spawn timing tracking was not available in 2017, hence only pre-spawn movement were inferred for fish # 117.

Timing of pre and post spawn movements is similar to the timing of migration and spawning observed in tributaries to Arrow Lakes Reservoir (Toth and Tsumura 1996, Drieschner et al. 2008). Location of spawning is not possible to determine from this study, but it appears that all four fish made directed movements to the upstream portions of the Columbia Reach and Upper Columbia areas of the Reservoir in the pre-spawn period. Arndt (2009) speculated that Rainbow Trout may migrate upstream entirely from the Reservoir, up the Columbia River to spawn in tributaries; however, the receiver installed on Kinbasket Reservoir at Quartz Creek (close to the confluence of the Columbia River) did not detect any of the tagged Rainbow Trout.

Although only four fish were inferred to make directed spawning movements, our receiver coverage can only detect broad scale movements of fish away from their home ranges. Our methods thus have limited ability to detect spawning migrations into tributaries within home ranges. Thus, while several of our tracked fish were detected during the spawning season, it is possible that they spawned in a tributary within their home range and we were unable to make inferences of spawning location or timing.

Tributary access, stream habitat and thermal suitability

Tributaries were surveyed during the general low pool period from May 2nd to May 3rd, 2017. Reservoir elevation ranged from 728.78 m to 728.93 m. Historically (1977 to 2014), the reservoir has experienced a mean reservoir elevation of 730.95 m, with a minimum elevation of 712.53 m and a maximum elevation of 737.14 m for this same low pool time period. As reservoir elevation was approximately 13 m higher than normal in 2015, surveys needed to be extended in future years with lower low pool elevations. In 2017 it was possible to extend the surveys of Harvey, Hugh Allan and Windfall Creek by 340 m, 480 m, and 260 m, respectively. In addition, Tsar Creek was surveyed, as this stream had been previously unvisited in Year 1 and Year 2 of study.

Two tributaries surveyed in 2017 may have at least partial fish migration barriers. An impassable fish migration barrier occurs on Tsar Creek, at an elevation of 735 m (Figure 13) and would be exposed during periods of low pool in most years of operation. Additional suspected fish migration barriers may be present lower in the drawdown zone of Tsar Creek and Windfall Creek (Figure 12, Figure 13). Windfall Creek in particular has five potential fish migration barriers, scattered throughout the drawdown zone, and thus tributary access may be an issue if adfluvial fish use this stream for spawning during periods of low reservoir elevations. However, it is unknown if either of these streams contain runs of adfluvial Rainbow Trout and would thus be impacted.

During the tributary surveys, the presence of suitable spawning substrates and their linear length were recorded. Gravel substrate that is approximately no larger than 10% of female spawner body length (Kondolf 2000) is considered suitable for spawning Rainbow Trout to construct their redds. Scattered spawning gravels were observed in the lower reaches of all streams surveyed (Photograph 2, Photograph 4, Photograph 6, Photograph 8). Although these patches were not extensive, they would be strongly affected by reservoir operations if they supported Rainbow Trout spawning, as their location within the drawdown zone occurs at elevations that would soon become inundated during the spring.

Rainbow Trout spawn in the spring, and the redds of these resident species are generally shallow, and thus extremely sensitive to scour in snowmelt dominated watersheds with steep channel (>3%) morphology and spring flood disturbance (Montgomery 1999, Fausch et al. 2001). The hydrology of tributaries in Kinbasket Reservoir is, without exception, snowmelt dominated. Most tributaries of Kinbasket Reservoir contain step-pool channel morphology with steep (>3%) gradients (Fielden et al. 1992) that likely limit the suitability of spawning habitat due to spring scour. Most tributaries surveyed in 2016 were on the border of or exceeded the 3% steepness threshold on average, with plane-bed, step-pool and cascade channel morphology. Based on gradient and channel morphology, these tributaries are likely to have marginal suitability for spawning except through limited reaches where gradient becomes shallower (e.g., lower reaches, APPENDIX B.2. – Stream elevation profiles through drawdown zone). In comparison to most tributaries sampled thus far throughout the study program, only Succour Creek and the Beaver River contain significant reaches of low gradient habitat (Figure 9)

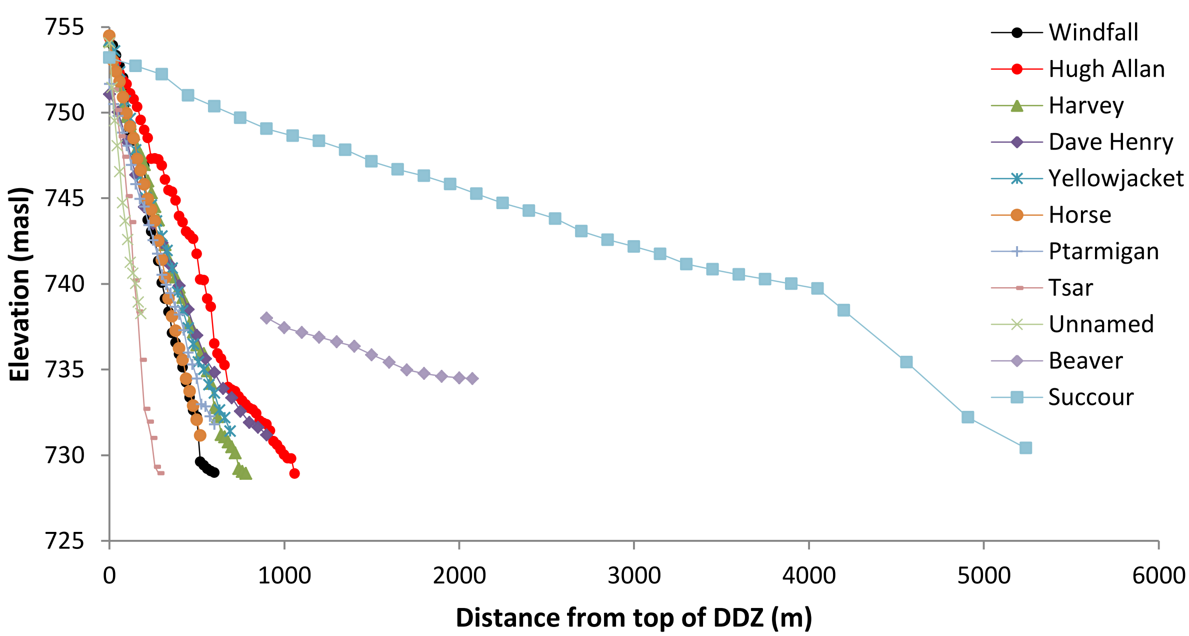


Figure 9. Longitudinal profile of all tributaries sampled throughout the CLBMON-7 study program.

Succour Creek was thermally suitable for Rainbow Trout spawning and incubation in the spring of 2015, and 2016 during the periods of lowest reservoir elevation, and continuing through the spring period of reservoir refilling. The inundation of potentially suitable spawning substrate was severe in 2015, but less severe in 2016, based on calculation of theoretical timing for initiation and cessation of spawning and fry emergence (Figure 4, Figure 5). These models indicated that reservoir refilling would inundate habitats suitable for spawning throughout the spawning and fry emergence periods, but in neither year were impacts so severe that all potentially suitable substrates were inundated.

Snorkel surveys

Succour Creek was selected for snorkel surveys, in order to determine spring occupation of the drawdown zone and spawning by Rainbow Trout. Due to logistical issues that limited access in 2017, only one survey was conducted, late (June) within the generalized possible spawning window for Rainbow Trout. Although the extensive drawdown zone of Succour Creek contains habitat that may be supportive of spawning during the periods of the survey, no mature Rainbow Trout were observed, and there was no evidence of redd construction in 2017. This supports similar findings in Years 1 and 2 of study, where no evidence of Rainbow Trout spawning was found in the drawdown zone.

Salmonid spawn timing is selected for in order to optimize survival to emergence and ensure that emergence timing occurs during a favourable period for growth (Brannon 1987, Quinn 2005). Given the expected timing of first emergence, it is possible that Rainbow Trout are limited by rapidly escalating temperatures or inundation prior to emergence for most spawning dates, for most locations in the drawdown zone. It is also possible that the drawdown zone suffers from extremely poor productivity of benthic invertebrates and does not provide initial first feeding opportunities for emergent fry (Brännäs 1995). Rainbow Trout, like all salmonids, return to natal areas to spawn. It is possible that the habitat is severely limited (for any of the above reasons or other reasons) to the extent that the local spawning population has been extirpated and cannot re-establish in the drawdown zone.

Fish abundance and diversity in the drawdown zone of Succour Creek in 2017 (June 15) was similar to the second survey conducted in 2016 (May 18), in which very large numbers of Largescale Sucker were observed. These fish were large bodied and exhibited colouration indicative of secondary sex characteristics displayed during spawning. Habitat characteristics in the stream are consistent with those reported as preferred by Largescale Sucker; however, inter-annual spawning timing differences may be explained by water temperatures, as the timing of optimal temperature range for spawning of this species occurred later in 2017 than in 2016 due to cooler spring temperatures (McPhail 2007). Succour Creek appears to support a large annually spawning population of adfluvial Largescale Sucker, a life history form that has not previously been reported to our knowledge. An interesting observation is the relatively high abundance of other species, particularly juvenile Rainbow Trout and Mountain Whitefish, during the same survey. The higher abundance of these species at this time could be explained by preference for the habitat at this time of year, migration through the drawdown zone, or feeding opportunities for eggs released during Largescale Sucker spawning events.

Conclusions and recommendations

In the third year of this study, several observations were made to further our understanding of Rainbow Trout life history and habitat use in Kinbasket Reservoir and its tributaries. Fish tagged with biotelemetry tags were observed to have individual differences in home range size and location, with the most frequent occupation of home ranges between the Confluence of the Columbia and Canoe Reaches, and the inlet into Kinbasket Lake (Figure 3). Some directed spawning migrations to and from home ranges appeared to occur, with several fish migrating upstream from Surprise Rapids in the Columbia Reach of the Reservoir in late March to early April, and returning between late May and mid-June. This may indicate movements of fish to spawning locations at the upstream end of the reservoir, and provides some data on the possible timing of pre and post spawn movements.

Capture success of large fish was low, and few Rainbow Trout were of sufficient size to be surgically implanted with biotelemetry tags, limiting sample size for tracking movements throughout the course of this study. Fish already tagged will not continue to provide data to these receivers in the subsequent year of study, as battery life of the tags will likely not extend into a fourth year of study. Additional tagging and tracking would have to be conducted to generate stronger conclusions (i.e., population level) about home range and pre and post spawn movements.

Tributary surveys in 2017 during the spring low pool period helped determine potential fish migration barriers that may be exposed and suitability of tributaries for spawning. One additional tributary was surveyed in Year 3 of the study, and three tributaries were revisited in order to survey a more extensive portion of the drawdown zone, as low pool reservoir elevations were significantly lower in 2017 than in 2015. Tsar Creek contains two fish migration barriers within the drawdown zone, and one of these appears to be impassable due to its vertical height, which should migration at all flow scenarios. Windfall Creek also appeared to have an additional potential fish migration barrier, bringing the total potential barriers on this stream to five, which are distributed throughout the drawdown zone. Windfall Creek therefore may have potential fish migration access issues during periods of low reservoir elevation. We did not find a significant amount of habitat suitable for Rainbow Trout spawning in the drawdown zone of tributaries surveyed, as most tributaries either contained unsuitable spawning substrate over the majority of the drawdown zone, or channel slopes exceeded those typically associated with spawning for the species; however, all tributaries contained some possible suitable substrate and a shallowing of channel slope at elevations close to reservoir elevations of ~729 m. Thus, some limited reaches of suitable habitat may be found at lower reservoir elevations within the DDZ. This may be due to a shallowing of slope in many tributaries as the pre-dam valley bottom is more fully exposed at very low pool reservoir elevations.

It is important to note that in recent years of reservoir operation (2001-2017) normal low pool reservoir elevation occurs at 726.9m, and the minimum reservoir elevation encountered was 712.4m. Thus, while our tributary surveys have captured the drawdown zone down to reservoir elevations of ~729-731 m, this does not capture the full extent of the drawdown zone and may underestimate the presence of barriers or availability of suitable spawning habitat at lower reservoir elevations.

In contrast to all other tributaries surveyed in this study thus far, Succour Creek contains extensive patches of suitable spawning substrate, shallow slopes, and a thermal regime predicted to be suitable for spawning throughout the drawdown zone. Snorkel surveys and detailed redd surveys did not reveal any spawning activity of Rainbow Trout in the drawdown zone of Succour Creek in 2017 despite the apparent physical suitability of the habitat. Results of this study suggest that currently unoccupied habitat that may be suitable could be impacted by reservoir operations, but the severity of impact varies depending on the reservoir operation and thermal regime of the stream. It is possible that reservoir operations or some other factor limit the establishment of a local spawning population in this habitat by interrupting the processes that support embryo and fry development or early growth. Monitoring should be continued in subsequent years to detect any spawning activity in the drawdown zone of this stream.

An additional year of surveys should be completed to increase the monitoring effort on Succour Creek, as well as continue the thermal suitability analysis to compare theoretical spawning and emergence timing to reservoir operations.

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APPENDIX A.1 – Rainbow trout tracking descriptions

Acoustic tag 112 (possible spawning migration detected):

Captured on September 22nd, 2014 in the Confluence area (Figure 3), its last detection in the first year of tracking was on April 2nd, 2015 at the Kinbasket Lake outlet. Throughout the pre-spawning period in 2015 it was detected by the Sullivan Bay entrance receiver (March 1-3) and then only by the Kinbasket Lake inlet receiver (March 4th to April 2nd). It was next detected on May 24th, 2015 by the Kinbasket Lake south inlet receiver. Throughout most of May 2015 it remained near the Kinbasket River outlet and then moved to the Sullivan Bay entrance and the outlet of the Kinbasket River at the end of May. It was last detected on June 13th, 2015 at the entrance to Sullivan Bay. Since the fish left its preferred home range of the Kinbasket Lake area, in an upstream direction between April 2nd and May 24th, it is possible that the fish travelled upstream to an unknown location to spawn and returned. This fish was not redetected in the third year of tracking.

Acoustic tag 113:

Captured on September 24th, 2014 in Kinbasket Lake, its last detection in the first year of tracking was on March 27th, 2015 at the Sullivan Bay entrance receiver. The fish's preferred home range appeared to be in the Kinbasket Lake area. This tag was not re-detected after this date or in the second year of tracking. Although this fish was detected in the pre-spawn period in both 2014 and 2015, no inferences can be made about directed movements since it did not appear to make any directed movements. This fish was not redetected in the third year of tracking.

Acoustic tag 115:

Captured on September 26th, 2014 in the Confluence area, its last detection in the first year of tracking was on October 4th, 2014 at the south outlet of the Canoe Reach. It was not detected again until July 17th, 2015 at the north outlet of the Columbia Reach. Therefore, movement information is not available for the pre-spawn and spawning periods. This fish remained near the north outlet of the Columbia Reach until July 21st, 2015 where it was detected by the one of the Canoe Reach receivers. From the beginning of August until the end of October it moved between the Wood Arm outlet, Canoe Reach and north outlet of Columbia Reach. It was not re-detected until April 30th, 2016 at the most upstream receiver in the Canoe Reach. The fish was the redetected in its home range on May 8, 2016, and remained in the confluence/forebay area until the date of its last detection on June 27, 2016. No directed movements occurred in and out of this fish's home range of the Canoe reach and confluence/forebay.

Acoustic tag 116:

Captured on October 2nd, 2015 in Kinbasket Lake and was first detected on October 2nd, 2015 by one of the receivers in the Sullivan Bay entrance. Detections were made by the Sullivan Bay entrance receivers until December 3rd. It was not re-detected until April 2nd, 2016 where it was again in the Sullivan Bay entrance. The final detection in Year 2 was on April 27th, 2016 in the Sullivan Bay entrance. In Year 3, the fish remained in this area from May 12, 2016 until its final detection on November 24, 2016. The home range of this fish for tracking information available was restricted to the Kinbasket Lake area, and the fish used this area throughout the generalized spawn period.

Acoustic tag 117 (possible spawning migration detected):
Captured on October 2nd, 2015 in Kinbasket Lake and was first detected on October 10th, 2015 by one of the receivers in the Sullivan Bay entrance. It remained in the area of the Sullivan Bay entrance until October 6th, and then moved to the Kinbasket Lake outlet. Regular movements were then made between the outlet of Kinbasket Lake, the Kinbasket River outlet and the Sullivan Bay entrance between October 6th and February 11th, 2016. On February 19th it was detected at the south inlet of Kinbasket Lake where it stayed for the remainder of February. On April 17th and 18th it was detected at the south inlet of Kinbasket Lake and Surprise Rapids, respectively. The final detection in Year 2 was made on April 19th, 2016 in Esplanade Bay. In Year 3, it was next redetected in Esplanade Bay on May 23rd, 2016, subsequently detected at Surprise Rapids on June 11th, and then subsequently detected in Kinbasket Lake on June 18th. In 2016, this fish thus moved out of its preferred home range of the Kinbasket Lake area by Mid-April and was making a directed, rapid movement upstream towards the inlet of the Reservoir, which could indicate a pre-spawn movement to an upstream spawning area, then returned to its home range in a directed movement between late May and mid- June. The fish then remained in its home range of the Kinbasket Lake until its last detection on February 2, 2017. The fish then initiated what appears to be another directed upstream pre-spawn movement in mid-April 2017, as it was detected at Surprise Rapids on April 18th, 2017, and then subsequently at Esplanade Bay on April 28th, 2017.

Acoustic tag 152 (possible spawning migration detected):
Captured on September 20th, 2014 in the Mica Dam forebay, its last detection in the first year of tracking was on March 29th, 2015 at the outlet of the Sullivan River after having spent the previous winter in the Wood Arm, ~50 km away . It was re-detected on May 26th and 27th, 2015 at the south inlet of Kinbasket Lake. Its final detection was recorded by both receivers gating the north outlet of the Columbia Reach on May 30th. This fish thus made a directed movement in the pre-spawn period of late March upstream, either to or passing beyond Kinbasket Lake to the Upper Columbia area of the reservoir, then returned towards its preferred home range of the Confluence and Wood Arm areas in late May of the same year. This fish was not redetected in the third year of tracking.

Acoustic tag 153:
Captured on September 21st, 2014 in the Confluence, its last detection in the first year of tracking was on October 5th, 2014 in Kinbasket Lake. This tag was not re-detected in the second or third years of tracking. No inferences can be made about spawning movements or home range.

Acoustic tag 155:
Captured on September 26th, 2014 in the Canoe Reach and was first detected on July 28th, 2015 at the most upstream receiver in the Canoe Reach. Regular detections were made by receivers throughout the Canoe Reach September 16th and then again on January 29th, 2016. From February 2nd until the 19th it was detected at the outlet of the Wood Arm, and was detected at the outlet of the Canoe Reach on

April 6, 2016. In the second year of tracking, it was only detected at the outlet of the Columbia Reach. The preferred home range of this fish appeared to be concentrated in the Confluence and southern portions of the Canoe Reach. No inferences can be made on directed spawning movements.

Acoustic tag 157 (possible spawning migration detected):

Captured on September 28th, 2015 in the confluence and was first detected on October 10th, 2015 in the outlet of the Canoe Reach. From October 13th until November 14th regular detections were recorded at the outlet of the Wood Arm. It was then found at the north outlet of Columbia Reach on November 15th and 16th, and then in Cummins River from November 17th until the 19th. Throughout December it traveled between the outlet of Kinbasket Lake, Sullivan Bay entrance and the inlet of Kinbasket Lake. It was next detected on March 7th, 2016 at the entrance of Sullivan Bay. From the beginning of March until mid-April it continued to be detected between the same three receiver locations. On April 18th it was recorded at the inlet of the southern Columbia Reach and then finally at Esplanade Bay (the penultimate receiver location in the upstream portion of the Upper Columbia) on April 25th. This fish thus moved out of its preferred, extensive home range of the Kinbasket Lake/Columbia Reach/Confluence area, making a directed movement upstream towards the inlet of the Reservoir by late April, which could indicate a pre-spawn movement to an upstream spawning area. In the second year of tracking, it was redetected at Esplanade Bay on May 29, 2016, then at Surprise Rapids on June 11, 2016. This could indicate the timing of post-spawn movement back to the reservoir. Its last detection was on July 20, 2017.

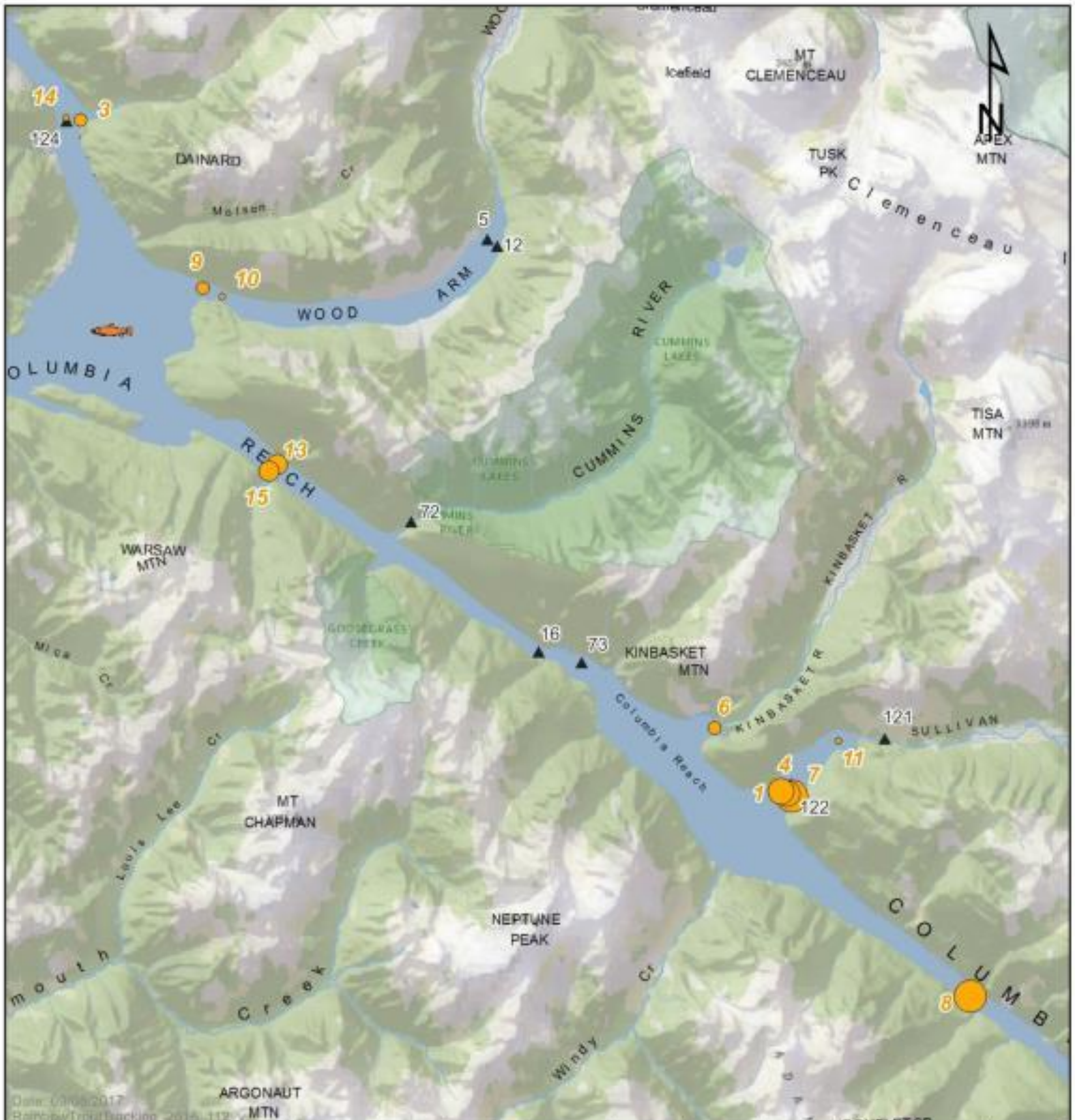
Acoustic tag 158:

Captured on September 28th, 2015 in the confluence and was first detected on October 29th, 2015 in the Canoe Reach. It was regularly detected in the Canoe Reach until mid-November. In mid-December it was detected at the north outlet of the Columbia Reach and then in the Cummins River until the end of December. It was then recorded at the Sullivan Bay entrance at the end of January 2016, and again at the beginning of April. In the second year of tracking, it was detected at the outlet of Kinbasket Lake and the Sullivan Bay entrance on May 4 and May 19, 2016, respectively. The fish was not detected making a directed spawning movement out of its home range of the Kinbasket Lake/Confluence areas.

Acoustic tag 159:

Captured on September 28th, 2015 in the confluence and was first detected on October 17th, 2015 in the Canoe Reach. It was regularly detected in the Canoe Reach until the end of October, and then again from December 20th until the 23rd. Between December 29th, 2015 and January 2nd, 2016 it was recorded at the north outlet of the Columbia Reach. It then traveled to the outlet of Kinbasket Lake, then Cummins River and Surprise Rapids throughout January. Its final detection in the first year of tracking was on January 20th, 2016 at the inlet of Surprise Rapids. It was only subsequently detected in the second year of tracking in this same are, both in May, 2016, and again in August, 2016. Limited detections are available to make inferences of home range. No inferences can be made on spawning movements.

APPENDIX A.2 – Rainbow trout tracking maps



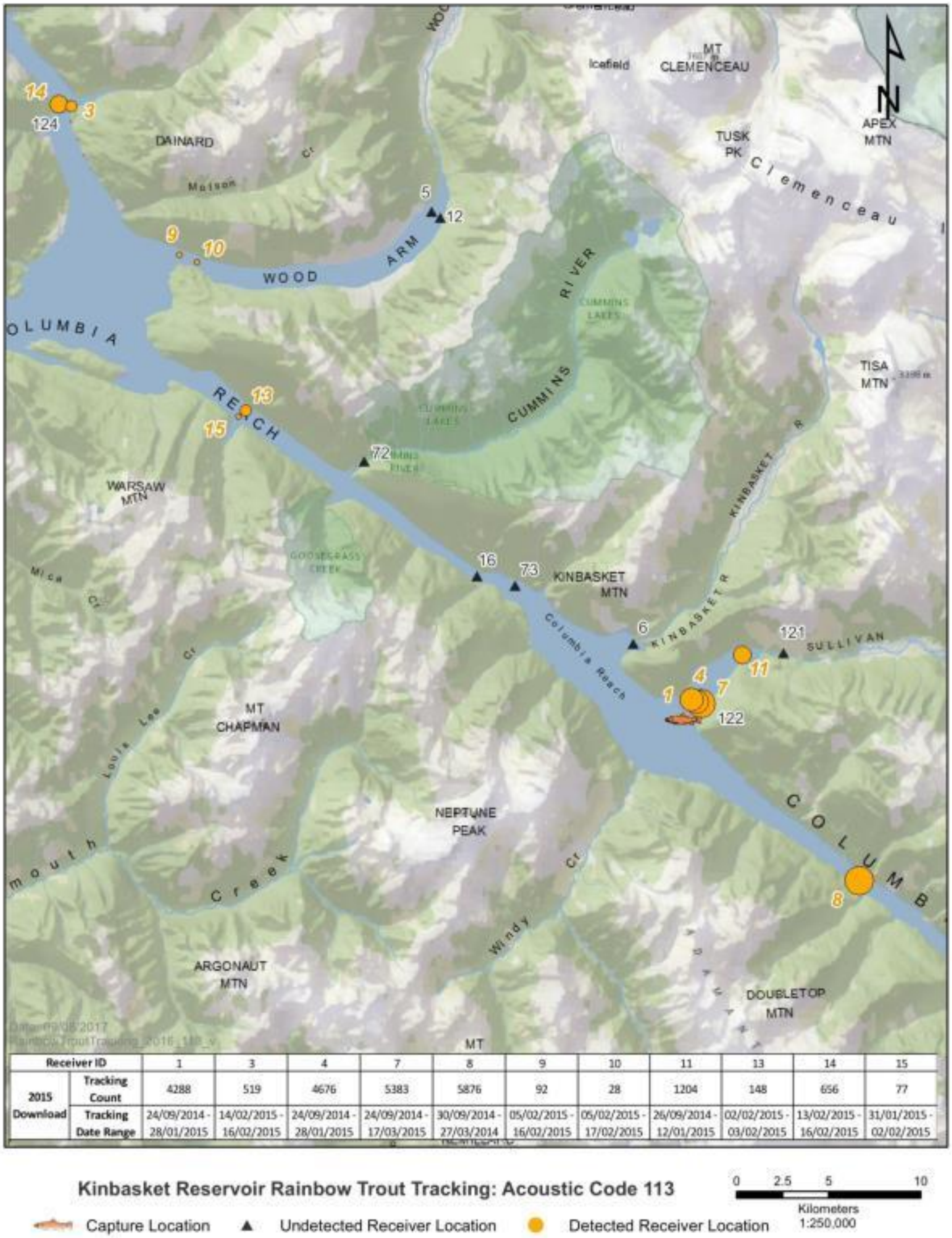
Receiver ID		1	3	4	6	7	8	9	10	11	13	14	15
2015 Download	Tracking Count	2001	305	2875	233	4328	5978	314	202	125	508	255	475
	Tracking Date Range	20/10/2014 - 30/01/2015	30/09/2014 - 04/10/2014	20/10/2014 - 16/02/2015	19/10/2014 - 02/11/2014	20/10/2014 - 03/03/2015	04/11/2014 - 02/04/2014	23/09/2014 - 05/10/2014	24/09/2014 - 26/09/2014	20/10/2014 - 06/01/2015	06/10/2014 - 09/10/2014	30/09/2014 - 04/10/2014	06/10/2014 - 09/10/2014
2016 Download	Tracking Count	36		32	132		1						
	Tracking Date Range	28/05/2015 - 13/06/2015		28/05/2015 - 13/06/2015	26/05/2015 - 04/06/2015		24/05/2015						

Kinbasket Reservoir Rainbow Trout Tracking: Acoustic Code 112

Capture Location ▲ Undetected Receiver Location ● Detected Receiver Location

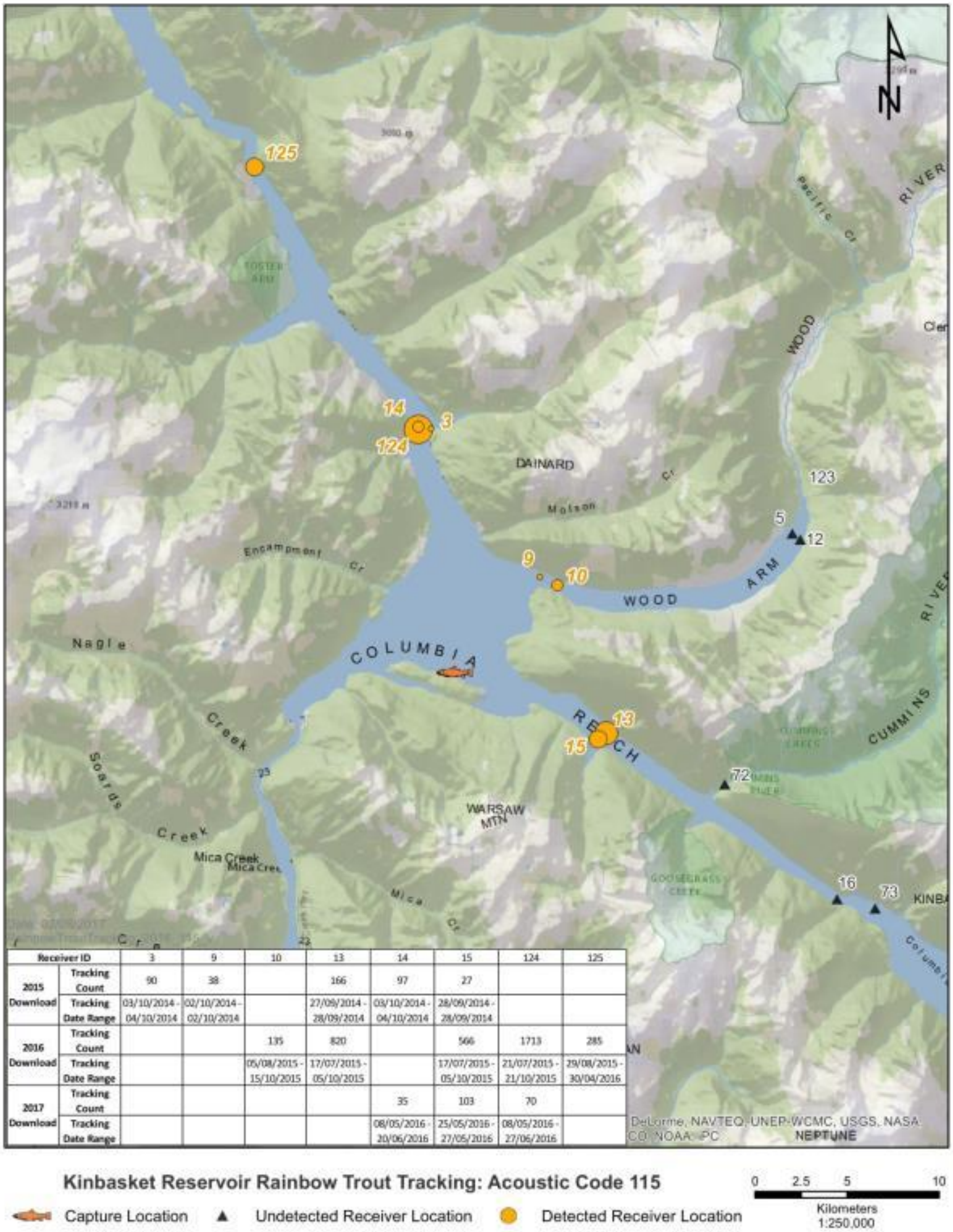
0 2.5 5 10 Kilometers 1:250,000

Figure A-1. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 112 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 22, 2014.



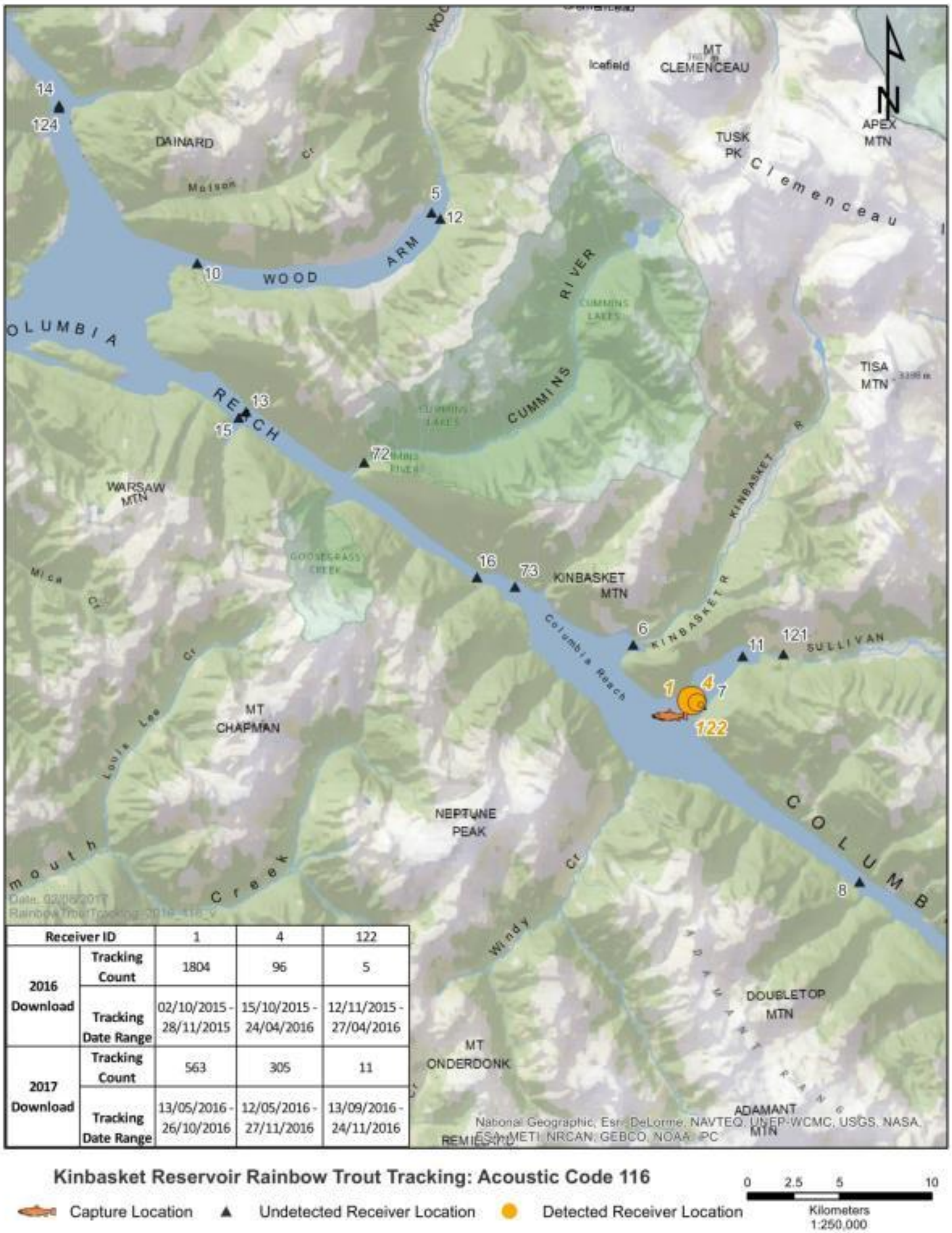
Receiver ID		1	3	4	7	8	9	10	11	13	14	15
2015 Download	Tracking Count	4288	519	4676	5383	5876	92	28	1204	148	656	77
	Tracking Date Range	24/09/2014 - 28/01/2015	14/02/2015 - 16/02/2015	24/09/2014 - 28/01/2015	24/09/2014 - 17/03/2015	30/09/2014 - 27/03/2014	05/02/2015 - 16/02/2015	05/02/2015 - 17/02/2015	26/09/2014 - 12/01/2015	02/02/2015 - 03/02/2015	13/02/2015 - 16/02/2015	31/01/2015 - 02/02/2015

Figure A-2. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 113 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 24, 2014.



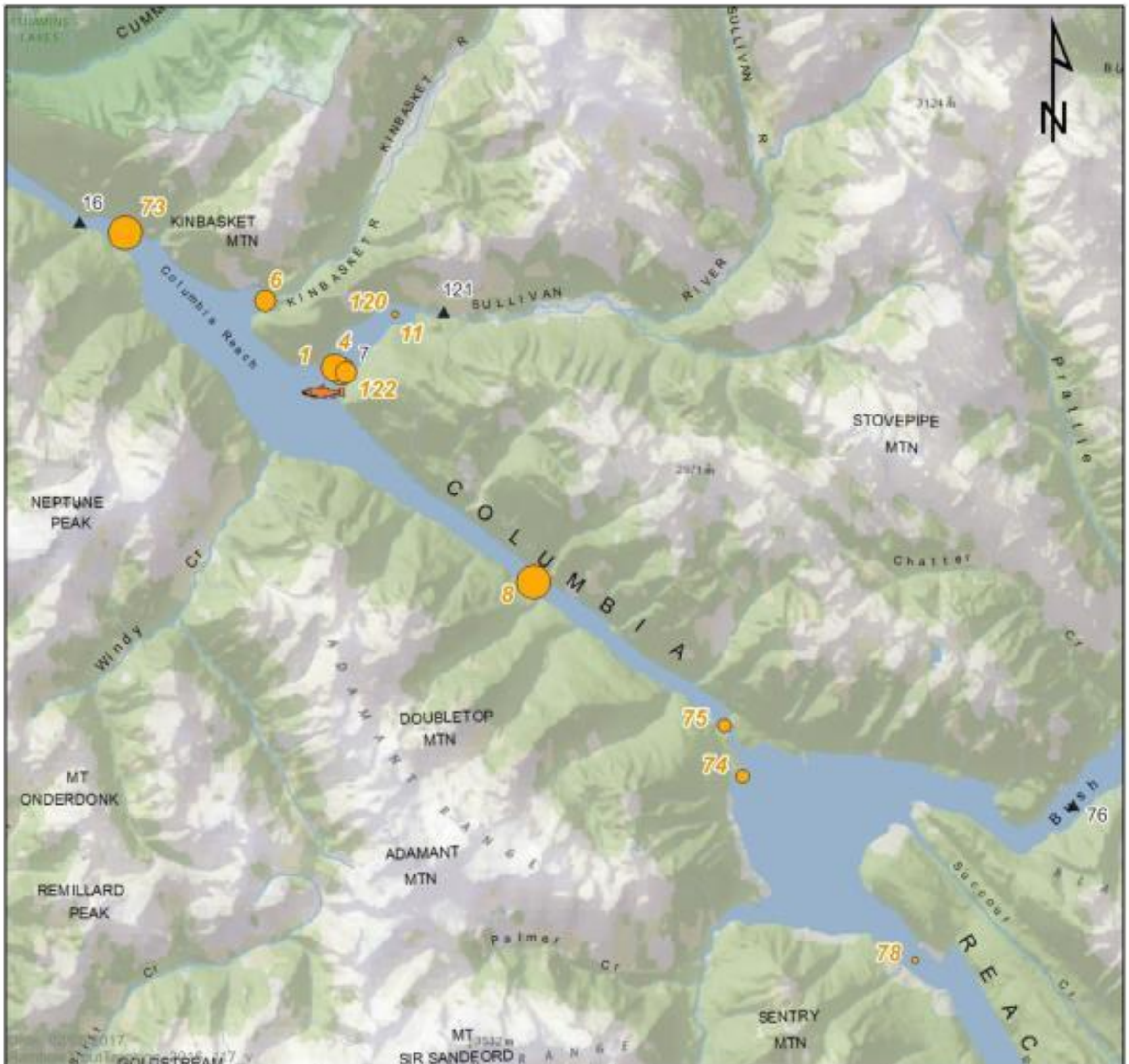
Receiver ID		3	9	10	13	14	15	124	125
2015 Download	Tracking Count	90	38		166	97	27		
	Tracking Date Range	03/10/2014 - 04/10/2014	02/10/2014 - 02/10/2014		27/09/2014 - 28/09/2014	03/10/2014 - 04/10/2014	28/09/2014 - 28/09/2014		
2016 Download	Tracking Count			135	820		566	1713	285
	Tracking Date Range			05/08/2015 - 15/10/2015	17/07/2015 - 05/10/2015		17/07/2015 - 05/10/2015	21/07/2015 - 21/10/2015	29/08/2015 - 30/04/2016
2017 Download	Tracking Count					35	103	70	
	Tracking Date Range					08/05/2016 - 20/06/2016	25/05/2016 - 27/05/2016	08/05/2016 - 27/06/2016	

Figure A-3. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 115 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 26, 2014.



Receiver ID		1	4	122
2016 Download	Tracking Count	1804	96	5
	Tracking Date Range	02/10/2015 - 28/11/2015	15/10/2015 - 24/04/2016	12/11/2015 - 27/04/2016
2017 Download	Tracking Count	563	305	11
	Tracking Date Range	13/05/2016 - 26/10/2016	12/05/2016 - 27/11/2016	13/09/2016 - 24/11/2016

Figure A-4. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 116 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on October 2, 2015.



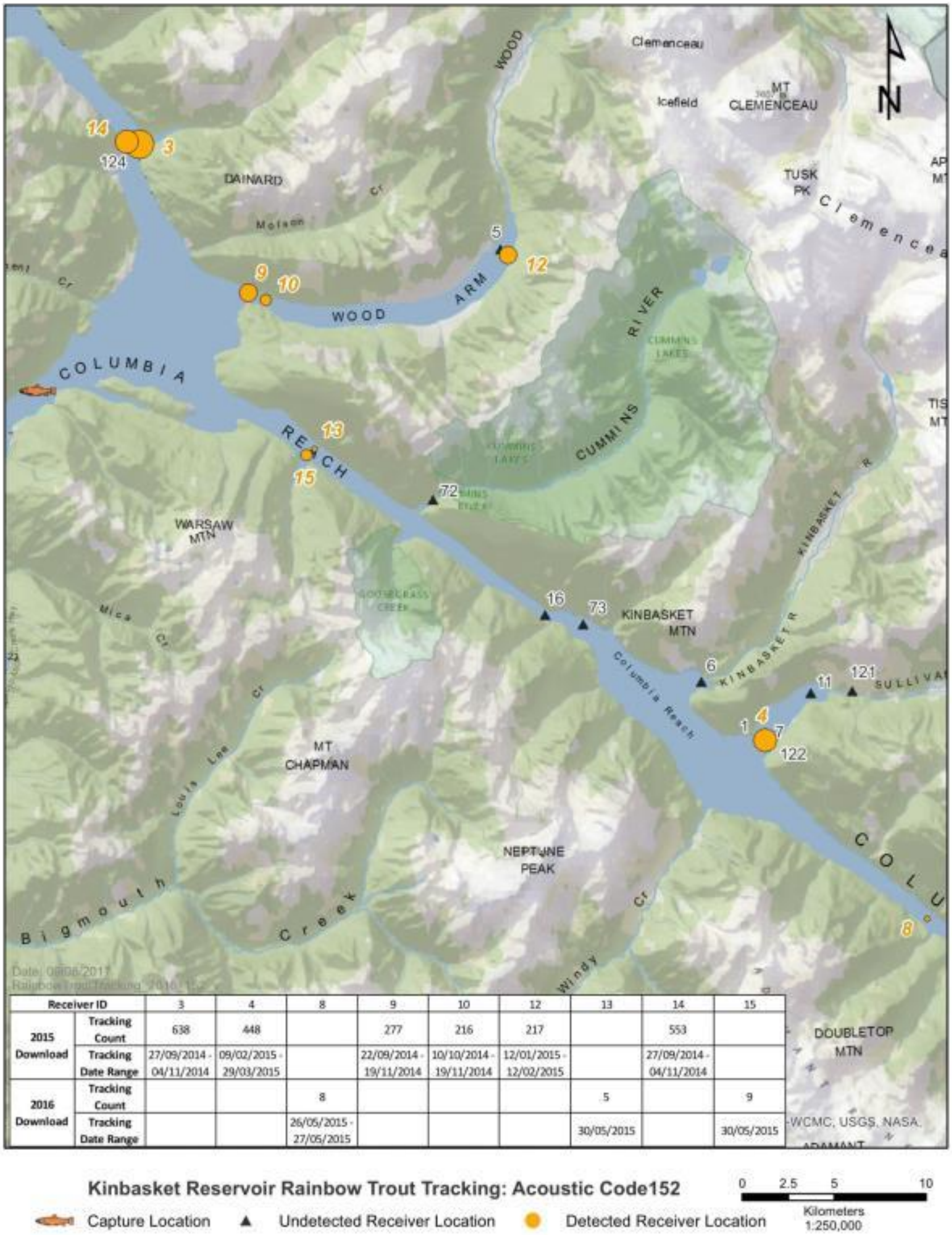
Receiver ID		1	4	6	8	11	73	74	75	78	122
2016 Download	Tracking Count	1061	1256	816	2035		783	92	404	2	664
	Tracking Date Range	02/10/2015 - 11/02/2016	02/10/2015 - 10/06/2016	09/10/2015 - 09/01/2016	21/10/2015 - 17/04/2016		06/10/2015 - 10/01/2016	15/03/2016 - 19/04/2016	15/03/2016 - 18/04/2016	19/04/2016	02/10/2015 - 09/02/2016
2017 Download	Tracking Count	746	1366	743	4075	56	2422	170	141	19	528
	Tracking Date Range	05/08/2016 - 02/02/2017	17/07/2016 - 02/02/2017	29/07/2016 - 25/01/2017	18/06/2016 - 08/02/2017	12/08/2016 - 05/12/2016	18/07/2016 - 16/01/2017	11/06/2016 - 14/06/2016	13/06/2016 - 14/06/2016, 13/12/2016 - 14/12/2016, 18/04/2017 - 21/04/2017	23/05/2016 - 31/05/2016, 28/04/2017 - 29/04/2017	17/07/2016 - 02/02/2017

Kinbasket Reservoir Rainbow Trout Tracking: Acoustic Code117

Capture Location ▲ Undetected Receiver Location ● Detected Receiver Location

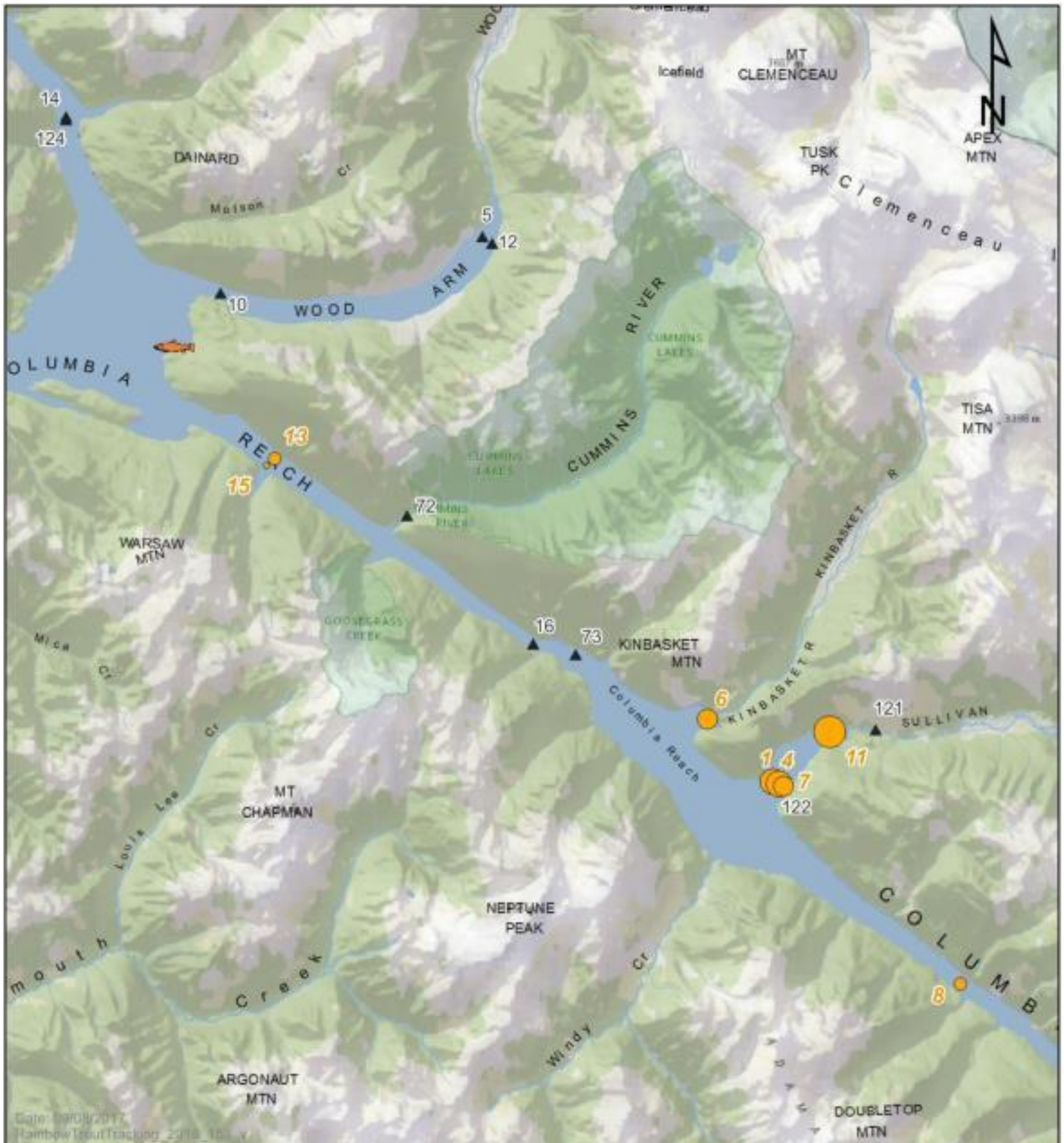
0 2.5 5 10 Kilometers 1:250,000

Figure A-5. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 117 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on October 2, 2015.



Receiver ID		3	4	8	9	10	12	13	14	15
2015 Download	Tracking Count	638	448		277	216	217		553	
	Tracking Date Range	27/09/2014 - 04/11/2014	09/02/2015 - 29/03/2015		22/09/2014 - 19/11/2014	10/10/2014 - 19/11/2014	12/01/2015 - 12/02/2015		27/09/2014 - 04/11/2014	
2016 Download	Tracking Count			8				5		9
	Tracking Date Range			26/05/2015 - 27/05/2015				30/05/2015		30/05/2015

Figure A -6. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 152 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 20, 2014.



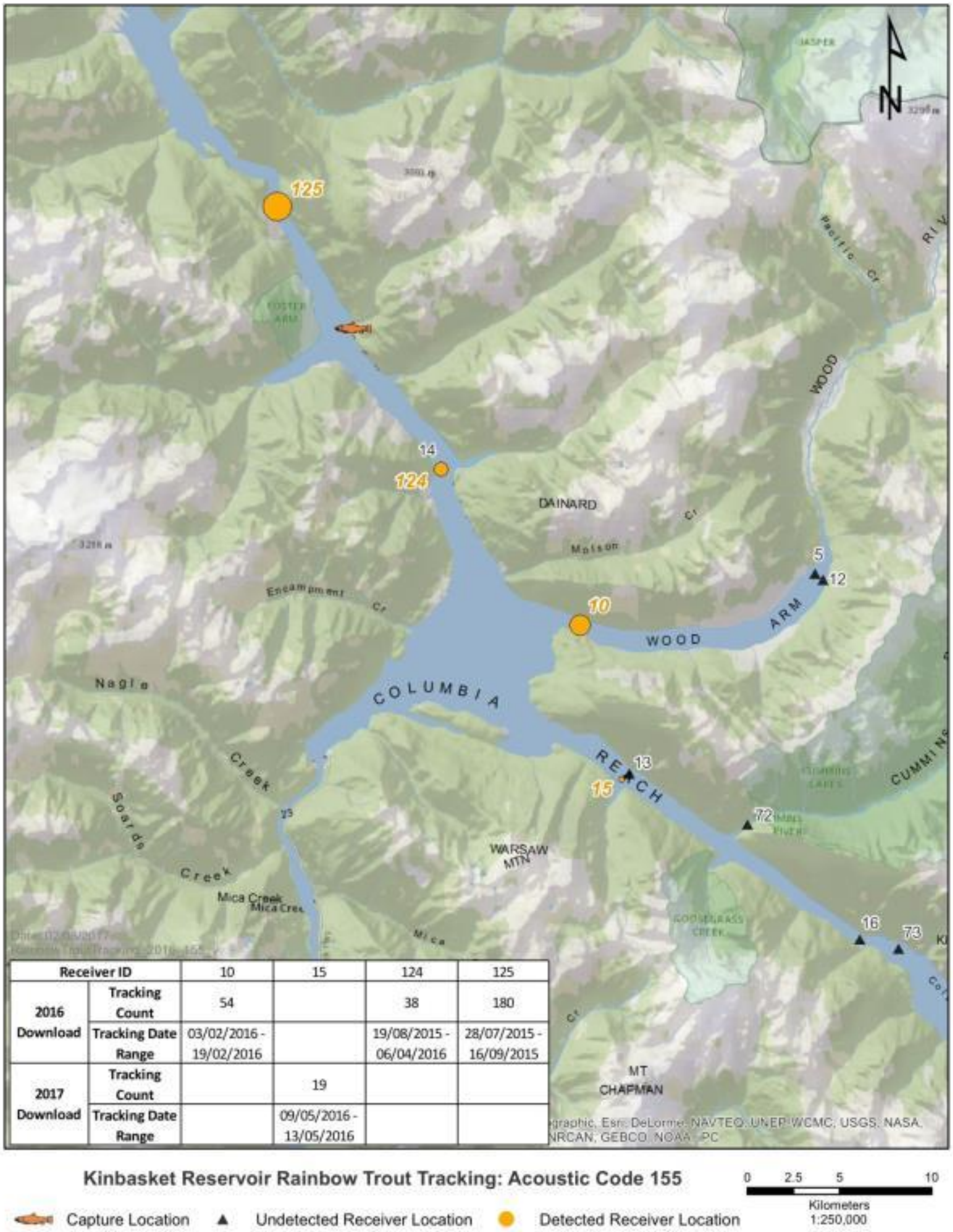
Receiver ID		1	4	6	7	8	11	13	15
2015 Download	Tracking Count	34	34	10	27	6	54	6	2
	Tracking Date Range	02/10/2014 - 05/10/2014	02/10/2014 - 05/10/2014	02/10/2014 - 02/10/2014	02/10/2014 - 05/10/2014	05/10/2014 - 05/10/2014	03/10/2014 - 04/10/2014	29/09/2014 - 29/09/2014	29/09/2014 - 29/09/2014

Kinbasket Reservoir Rainbow Trout Tracking: Acoustic Code 153

0 2.5 5 10 Kilometers 1:250,000

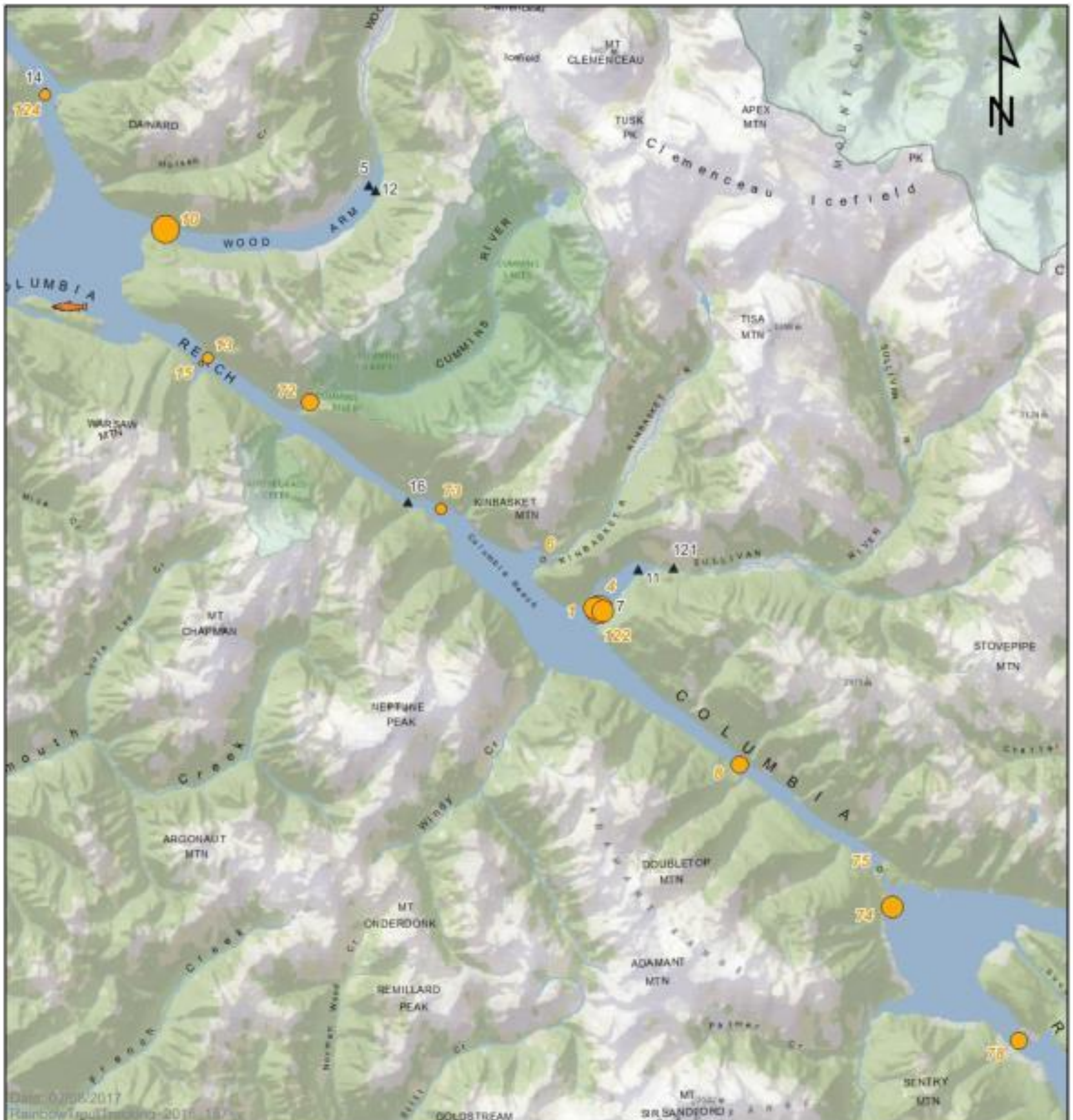
Capture Location ▲ Undetected Receiver Location ● Detected Receiver Location

Figure A-7. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 153 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 21, 2014.



Receiver ID		10	15	124	125
2016 Download	Tracking Count	54		38	180
	Tracking Date Range	03/02/2016 - 19/02/2016		19/08/2015 - 06/04/2016	28/07/2015 - 16/09/2015
2017 Download	Tracking Count		19		
	Tracking Date Range		09/05/2016 - 13/05/2016		

Figure A-8. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 155 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 26, 2014.



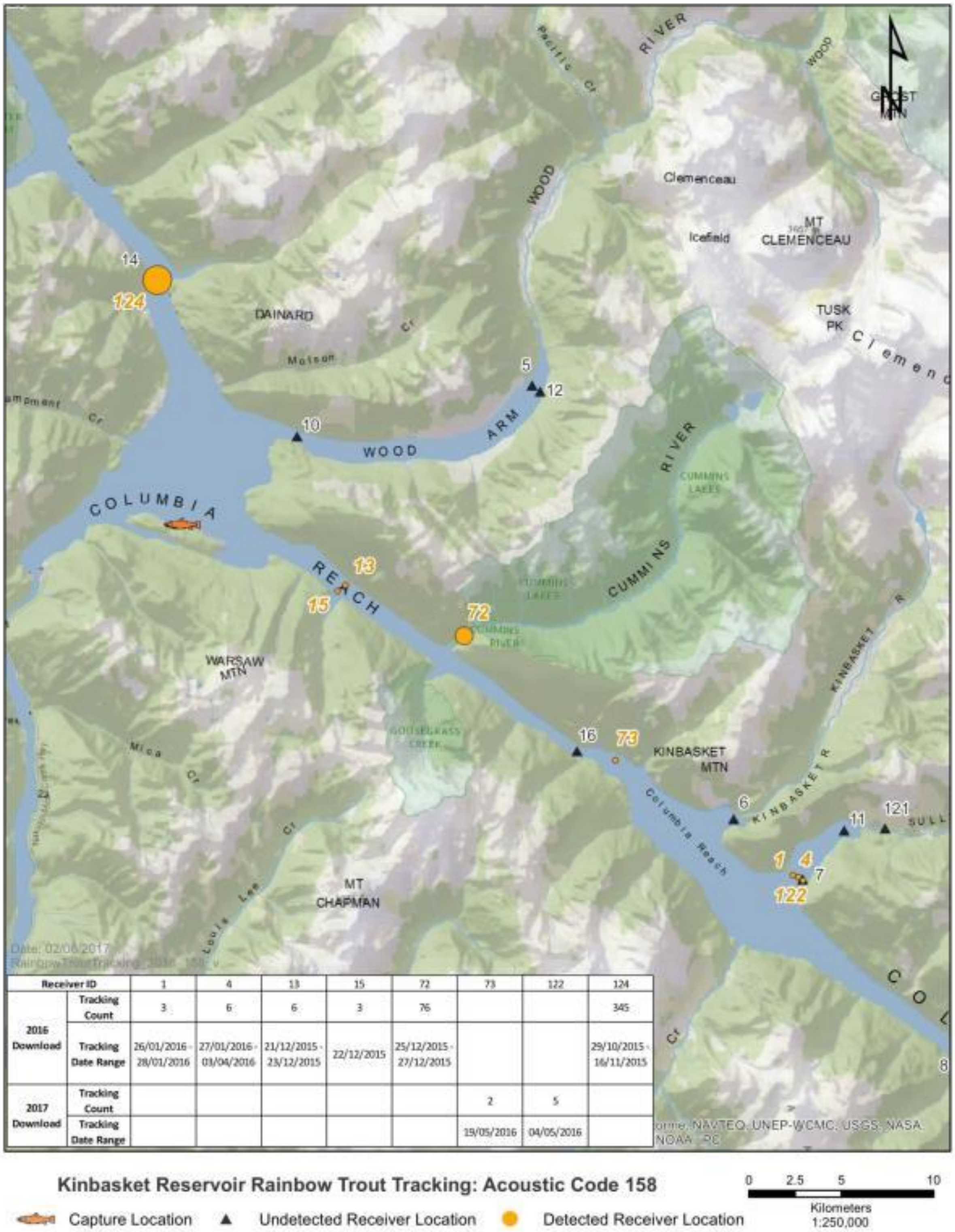
Receiver ID		1	4	6	8	10	11	15	72	73	74	75	78	122	124
2016 Download	Tracking Count	193	319	6	158	665	36	2	79	42	1	6	15	188	30
	Tracking Date Range	08/12/2015 - 11/03/2016	08/12/2015 - 12/04/2016	08/12/2015	18/12/2015 - 17/04/2016	13/10/2015 - 14/11/2015	15/11/2015 - 16/11/2015	16/11/2015 - 21/11/2015	17/11/2015 - 05/12/2015	07/12/2015 - 28/03/2016	23/04/2016	18/04/2016	25/04/2016	08/12/2015 - 12/04/2016	10/10/2015 - 11/10/2015
2017 Download	Tracking Count										170		38		
	Tracking Date Range										11/06/2016 - 14/06/2016		29/05/2016, 28/06/2016, 18/07/2016-20/07/2016		

Kinbasket Reservoir Rainbow Trout Tracking: Acoustic Code 157

Capture Location ▲ Undetected Receiver Location ● Detected Receiver Location

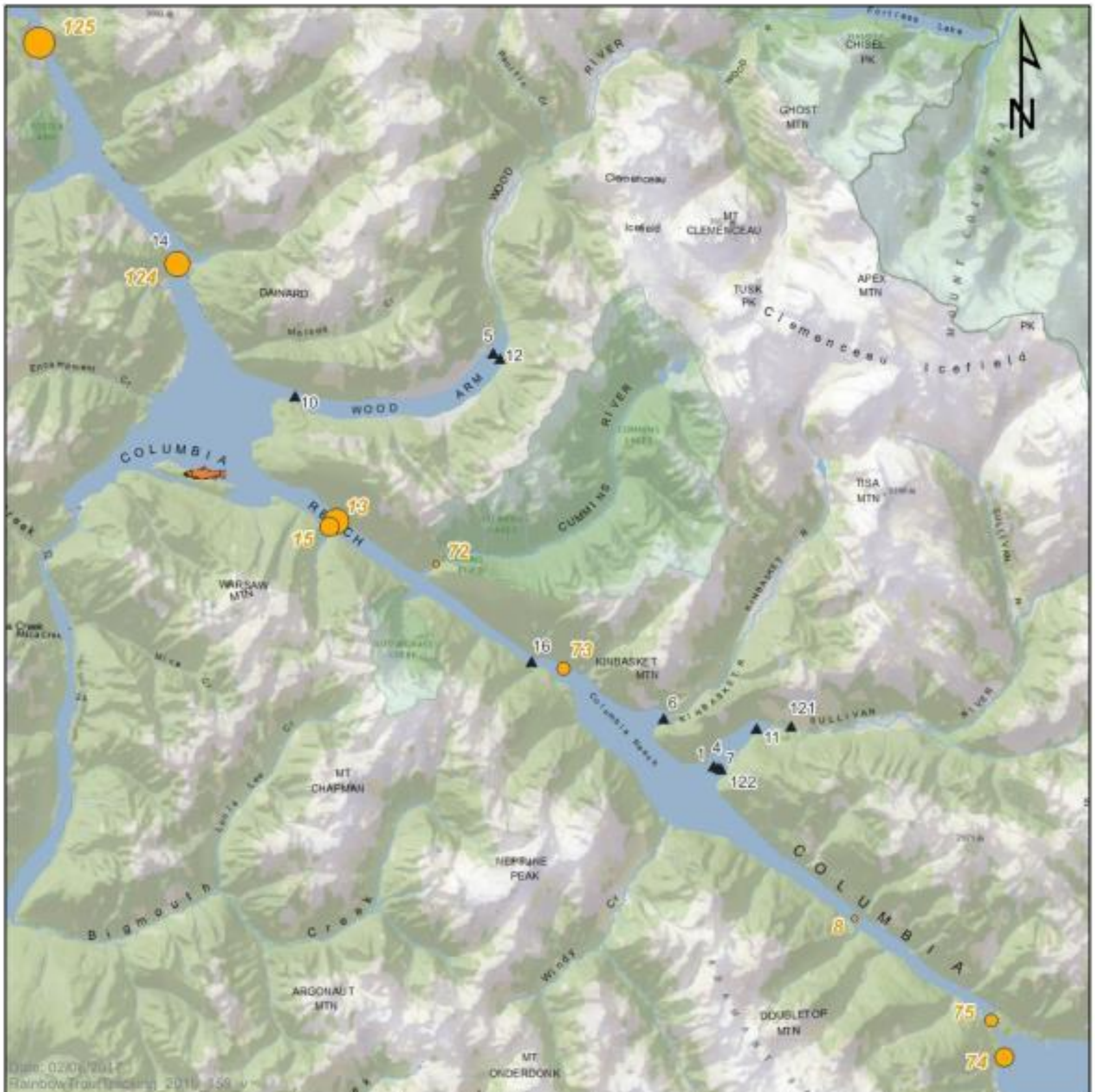
0 2.5 5 10 15 Kilometers 1:325,000

Figure A-9. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 157 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 28, 2015.



Receiver ID		1	4	13	15	72	73	122	124
2016 Download	Tracking Count	3	6	6	3	76			345
	Tracking Date Range	26/01/2016 - 28/01/2016	27/01/2016 - 03/04/2016	21/12/2015 - 23/12/2015	22/12/2015	25/12/2015 - 27/12/2015			29/10/2015 - 16/11/2015
2017 Download	Tracking Count						2	5	
	Tracking Date Range						19/05/2016	04/05/2016	

Figure A-10. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 158 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 28, 2015.



Receiver ID		8	13	15	72	73	74	75	124	125
2016 Download	Tracking Count	1	28	27	1	2	14	7	52	384
	Tracking Date Range	12/01/2016	29/12/2015 - 02/01/2016	29/12/2015 - 30/12/2015	08/01/2016	06/01/2016	14/01/2016 - 20/01/2016	14/01/2016	17/10/2015 - 23/12/2015	21/10/2015 - 20/12/2015
2017 Download	Tracking Count							2		
	Tracking Date Range							11/05/2016, 01/08/2016		

Kinbasket Reservoir Rainbow Trout Tracking: Acoustic Code 159

Capture Location ▲ Undetected Receiver Location ● Detected Receiver Location

0 2.5 5 10 15 Kilometers 1:340,000

Figure A-11. Map showing the acoustic receivers in Kinbasket Reservoir that detected tag 159 and their tracking date ranges. Detected receiver location points are sized according to their relative number of detections. Capture and tag implantation occurred on September 28, 2015.

APPENDIX B.1. – Tributary photographs

Photograph 1. Harvey Creek approximately 560m (~735 m elevation) from the top of the drawdown zone (May 3rd, 2017).

Photograph 2. Harvey Creek approximately 720m (~730 m elevation) from the top of the drawdown zone, near the reservoir (May 3rd, 2017).

Photograph 3. Hugh Allan Creek, approximately 680 m from the top of the drawdown zone (~ 734 m elevation). Photo taken May 2nd, 2017.

Photograph 4. Hugh Allan Creek, approximately 1,000 m from the top of the drawdown zone (~ 730 m elevation), near the reservoir. Photo taken May 2nd, 2017.

Photograph 5. Windfall Creek, approximately 360 m from the top of the drawdown zone (~ 737 m elevation). Photo taken May 2nd, 2017.

Photograph 6. Windfall Creek, approximately 580 m from the top of the drawdown zone (~ 729 m elevation), near the reservoir. Photo taken May 2nd, 2017.

Photograph 7. Tsar Creek, near the top of the drawdown zone (~ 751 m elevation). Photo taken May 3, 2017.

Photograph 8. Tsar Creek, approximately 280 m from the top of the drawdown zone (~ 729 m elevation), near the reservoir. Photo taken May 2nd, 2017.

APPENDIX B.2. – Stream elevation profiles through drawdown zone

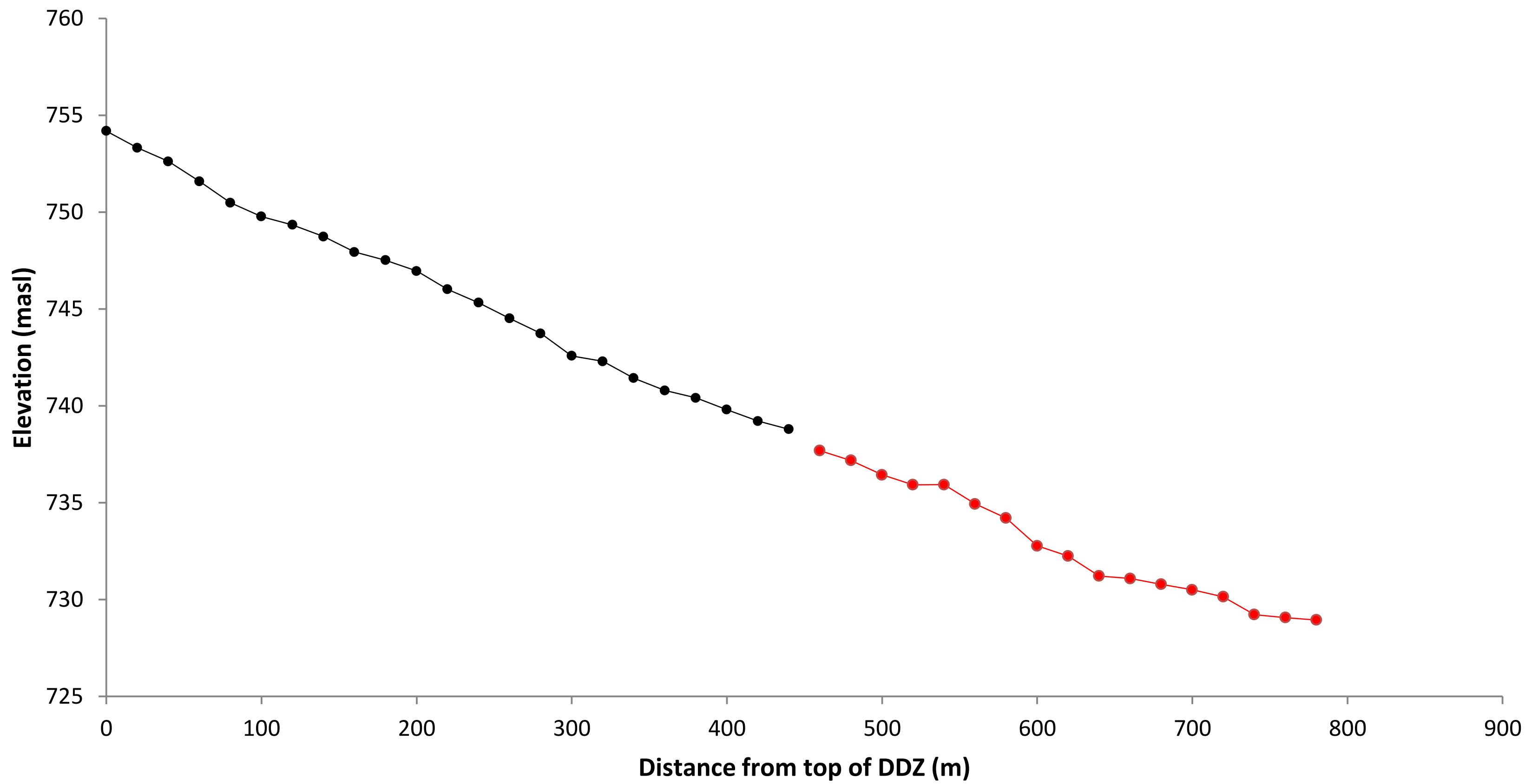


Figure 10: Longitudinal profile of stream elevation for Harvey Creek. Black markers are transect points taken in the 2015 survey, and red markers are points taken in the 2017 survey.

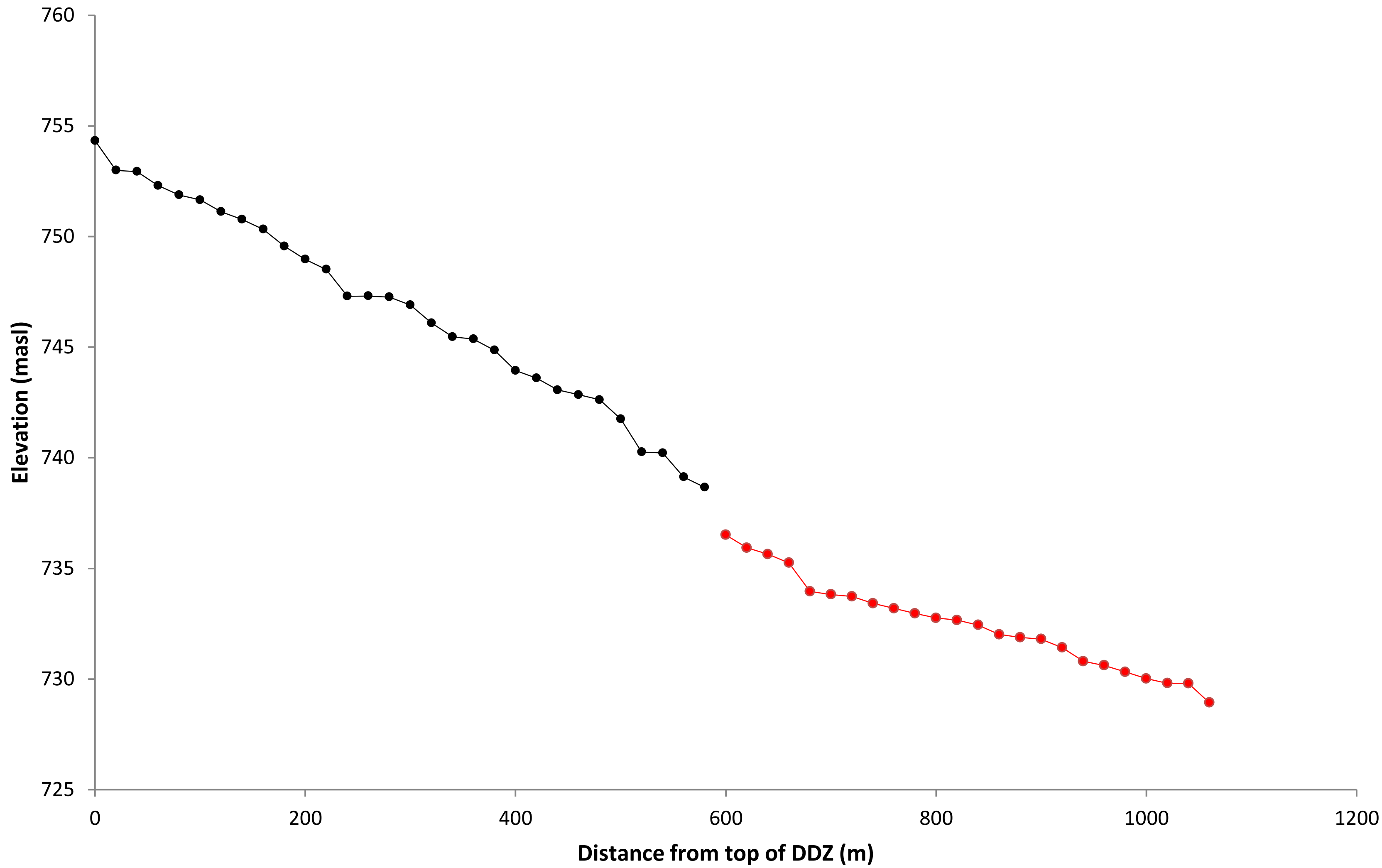


Figure 11: Longitudinal profile of stream elevation for Hugh Allan Creek. Black markers are transect points taken in the 2015 survey, and red markers are points taken in the 2017 survey.

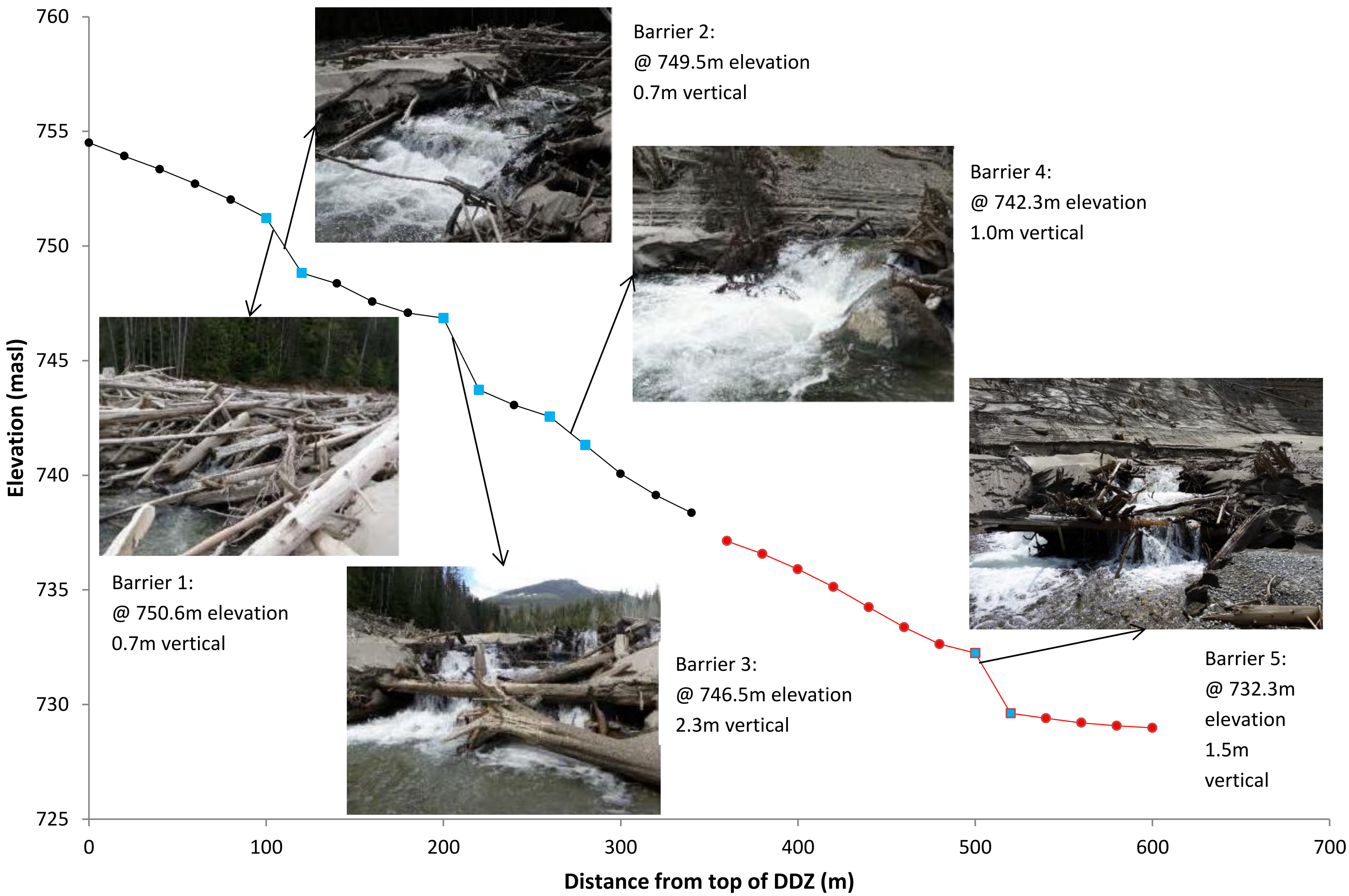


Figure 12: Longitudinal profile of stream elevation for Windfall Creek. Black markers are transects taken in the 2015 survey, and red markers from the 2017 survey. Barriers are found in transects bounded by blue markers. Barrier photos and information are embedded in the figure.

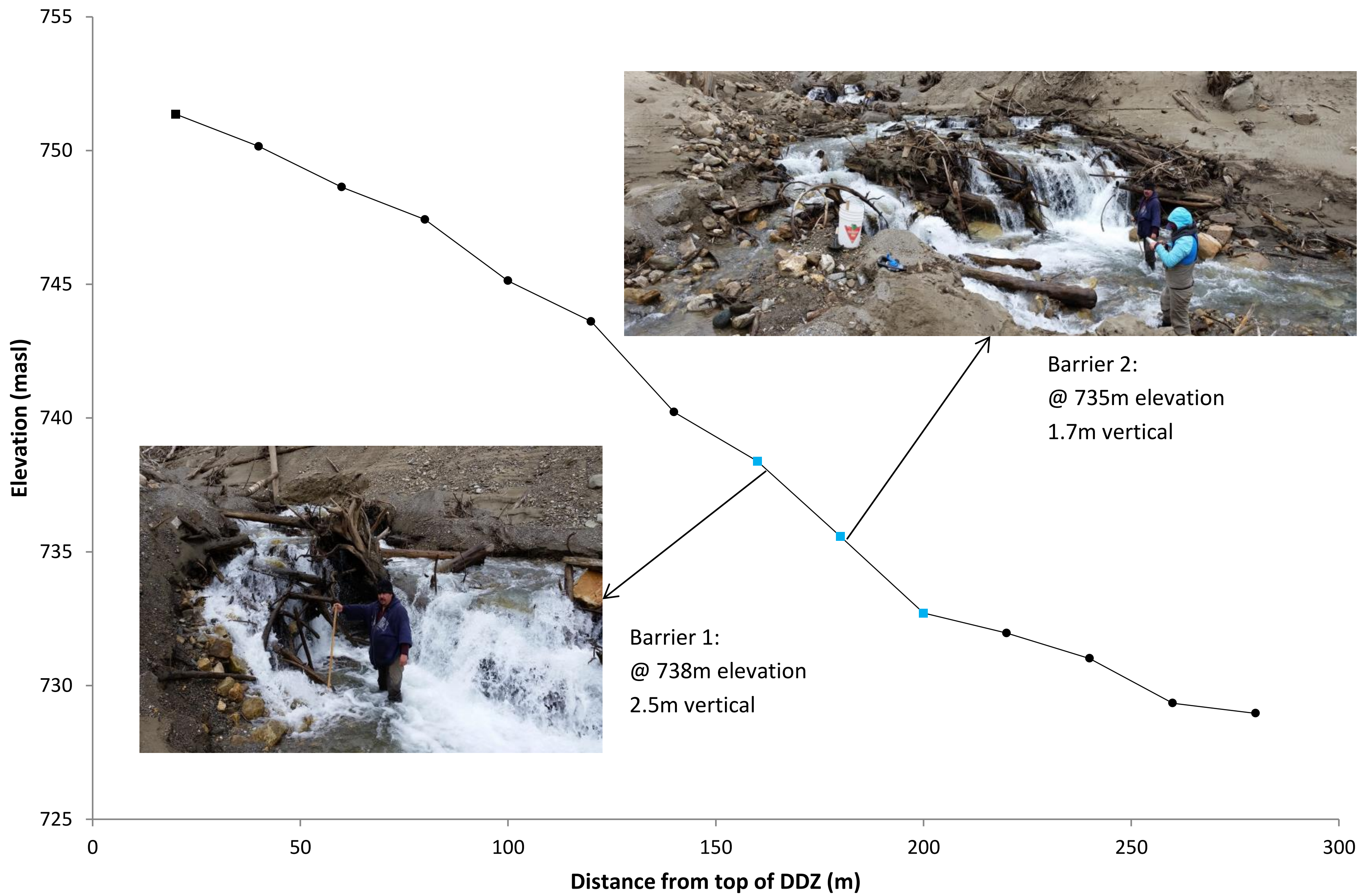


Figure 13: Longitudinal profile of stream elevation for Tsar Creek from the 2017 survey. Barriers are found in transects bounded by blue markers. Barrier photos and information are embedded in the figure.