Response to BGD-11-C4441-2014

Summary of Comments on Beaded streams of Arctic permafrost landscapes

Comment from Referee:

General Comments: This is an important paper in that very little research has ever been published on beaded streams in the arctic region and yet these streams are one of the more common stream types in this environment. Until this paper we have known very little about their distribution and characteristics. The authors have done a nice job utilizing three nested spatial frameworks – from pan-arctic to regional to watershed – to explore the nature of beaded streams. The analyses are straightforward and the report narrative is reasonably clear, with appropriate figures and tables. There are, however, a number of revisions that need to be made before this manuscript is published, largely for clarity. These changes are detailed on the following specific comments with finer-scale editorial suggestions in the accompanying annotated PDF. One of the most important changes that needs to be made is to explain more clearly how the pan-arctic survey of Google Earth images actually proceeded. It seems, but is not clear, that a complete, manual survey of the entire pan-arctic region was done. This seems like a monumental undertaking and if that is what was done, kudos. But some other systematic sub-sampling survey was done, this was not adequately explained in the methods and should be. The scale at which the scanning survey was done should be identified. Was a consistent scale used throughout? If not, why not? The justification for the use of RWT needs to be clarified. RWT is not conservative it is degrades or sorbs onto OM and that needs to be more clearly stated. It would be helpful in the discussion about the stability of beaded stream structure to place this in the context of their stability relative to stability of other hydrogeomorphic features in permafrost-dominated landscapes. What is the turnover time of a thaw lake or a river meander? In the context of these other features, are beads more or less stable? I have noted a few suggestions to improve several figures. The manuscript should be thoroughly proofed. There were numerous grammatical errors, several of which have been noted in the annotated PDF. In addition I've offered several editorial suggestions.

Author's Response: We appreciate the reviewer's recognition of the value of this work in light of the abundance of these ecosystems in the arctic relative to published studies. We agree that there was need for improved clarity and numerous grammatical errors throughout and we appreciate the reviewer's attention in pointing these out. The three points raised here that need to be addressed 1) GE survey, 2) RWT tracer tests, and 3) comparison with stability of other thermokarst landforms are all important ones that we have taken care to address.

Author's Changes to the Manuscript:

1 – GE Survey: This survey was in fact a pan-arctic survey of all areas in the continuous permafrost zone, but only areas with high resolution imagery, which particularly in Canada and Russia limited the actually area surveyed greatly. We explained this originally, but not in a quantitative sense and this was misleading. Because of this, we have added a table documenting these differences in areas surveyed and used these data to make estimates of the total number of stream networks and corresponding drainage densities. Additionally we have eliminated the pan-arctic map, because this could be very misleading if not taken in the context of available imagery (we wanted to add polygons to this map showing these areas, but the very patchy nature of this imagery made it very hard to see). Instead we added three images

from Google Earth showing examples of beaded networks from different countries from high resolution imagery.

Text in methods now reads (**P3, L64-83**): The Circum-Arctic survey utilized imagery available in GE to identify channels with beaded morphology. This analysis focused on the continuous permafrost zone north of 66^{o} latitude. We utilized the historical image browser function in GE to access the highest resolution imagery (< 5-m) possible for a given region. This analysis focused on portions of Alaska (U.S.A.), Siberia (Russia), and northern Canada totaling approximately 4.5 million km^2. We found that most channels with beaded morphology could be identified when scanning images at 1:6,000 when the imagery was had a resolution of 5-m or finer and was mostly snow-free. The availability of high resolution, snow-free imagery in Alaska was quite good, covering 80% of the continuous permafrost zone surveyed. In Russia and Canada, the availability of such imagery was much lower, 11% and 9%, respectively, as of 2013 (Table 1). For this survey, zoomed in on each channel with beaded morphology for closer inspection and verification and marked its course at the furthest downstream point on the network of beaded channels. Surface elevation, latitude, and classes of permafrost ground ice were attributed to each point using thematic datasets for panarctic (Brown et al., 1998) and Alaska-focused permafrost and ground ice distribution (Jorgenson et al., 2008) and surface elevation. In order to compare among regions with differing extents of sufficient imagery, we extrapolated the number of surveyed streams based on the proportion of high resolution imagery available to estimate the total number of beaded stream networks in the Circum-Arctic continuous permafrost zone (Table 1). We additionally estimated drainage density of beaded channels based on assuming an average network length of 10 km, which results in only a broad regional average and definitely varies considerable on finer scales.

2 – RWT Tracer Tests: This is correct that RWT is not truly conservative and we originally neglected this in the text, which now reads (**P8, L215-230**): Rhodamine WT (RWT), a pink fluorescent dye, was used as a water tracer because it can be detected at low concentrations and only small quantities are required to reach target concentrations, which is an important practical consideration for remote field sites. RWT has low biological reactivity, yet does sorb to organic matter and begins photodegrading after several days of sunlight exposure at low concentrations (Vasudevan et al., 2001). Thus, RWT is not truly conservative, however is widely use to characterize channel hydraulics and transient storage processes, including previous work in Arctic beaded streams (Zarnetske et al. 2007). Based on targeted downstream peak concentrations of 30 ppb, we made pulse additions of RWT at reach heads and monitored concentration at the reach bottom using a YSI 6600-V2 water quality sonde with a RWT probe. This experiment typically lasted a day or longer to account for all tracer moving through the system. RWT tracer data were then fit with the model One-dimensional Transport model with In-channel Storage and Parameterization (OTIS-P) to estimate advective channel area (A), storage zone area (A_S), dispersion (D), and the storage exchange coefficient (α) (Runkel, 2000). Percent RWT recovery averaged 81% with an average sorption coefficient (λ) of 1×10^{-5} used to account for this loss downstream.

3 – Comparison with other Thermokarst Landforms: This is a very good idea and we've added comparison with thermokarst lakes and alluvial rivers (**P16, L458-464**): For comparison to other thermokarst landforms, thermokarst lakes in this region also progressively expand their lake basins, 0.10 m/yr on average (Jorgenson and Shur 2007), but can drain catastrophically if a shoreline expands beyond a lower gradient or is breached by another lake or migrating river

(Grosse et al. 2013). Alluvial channels on the ACP are considered highly dynamic often with very high rates of bank erosion due to interactions with permafrost such that major changes in channel course can occur over short time periods (Scott 1978).

However, besides this information we aren't aware of any quantitative data on TK landform turnover rate that could be incorporated (and no references were provided by the reviewer).

Comment from Referee:

Specific Comments Page: 5 I presume that only a subset of the total arctic area was survey. How were scenes selected for quantification? Were they randomly selected? What % of the area was sampled? Were all analyzed at the same scale?

Author Response: As detailed above we did actually conduct a full pan-arctic survey, but only where high res imagery existed.

Author's Changes to the Manuscript: see above changes with respect to GE survey.

Comment from Referee:
Page: 7 If these are relevant they should be identified. "...as described below in the next section"?

Author's Changes to the Manuscript: Agreed and this was added **(P4, L124**).

Comment from Referee:
Page: 8 Of a total drainage length of what for each watershed?

Comment from Referee:
Page: 11 Vague. What measurements?
All of this is true, but phrase does not make sense. If RWT photodegrades it can't be conservative. In addition, the primary complaint about RWT is the it does stick somewhat to organic matter. Thus, beads would be one environment in which this could be a particular problem. The authors could put bounds on whether this is a large problem or not by summing the mass flux of RWT to identify how much of the tracer that was added upstream was recovered downstream. It is important quantify this because a loss of tracer due to sorption or photodegration will appear as permanent loss of tracer (and water) from the system.

Author's Changes to the Manuscript: see changes above with respect to this concern.

Comment from Referee:
Page: 12 But how were these "found"? Was the entire pan-arctic region searched quantitatively? Or was a subsampling regime used? If sub-sampling, how? The method of searching matters with respect to how best to extrapolate to the pan-arctic. If you look until you find beads, count them, and then extrapolate to the entire region, this could vastly over estimate the coverage compared to random sampling of the region to identify how frequently beaded streams arise in that landscape type. What method was used to search?

Author's Changes to the Manuscript: see changes above with respect to this concern.

Comment from Referee:
Page: 13 It would be helpful to explain why this is perplexing to the authors, given that the following explanations seem reasonable.
Is this a generally accepted statement? If so, an appropriate citation should be included.
If not, the statement should probably be qualified; i.e., "may be"

Author's Changes to the Manuscript: We agree that this was poorly worded and have made the following changes to read (**P11, L294-299**) This lack of channels with beaded morphology on the outer coastal plain is perhaps unexpected, given the ubiquitous presence of ice-wedge polygons in which beaded drainage forms. We have observed however that most channels in this region tend to take a plane bed form without alluvial features, which may relate to very high pore ice content that in addition to wedge-ice makes soils in this regions extremely ice-rich, often exceeding 90% by volume (Brown, 1968).

Comment from Referee:
Page: 15 Fig 1a does not really help me understand this relationship. I see no lakes on Fig. 1a.

Author's Changes to the Manuscript: This is a very good point and we have added lakes to this figure (now figure 2) as well as showing the Fish Creek Watershed separately with lakes also indicated (Figure 3).

Comment from Referee:
There appears from Fig 1a to be quite high densities in the southern finger of Fish Creek.

Author Response: The densities in that region are not actually that high, but the channels are very short due to the drainage area shape, so indicating the channels with points was misleading here. Instead we've modified this figure (now Fig. 3) to show the full beaded channel courses so this is clearer.

Comment from Referee:
I don't think Fig. 5 really supports this statement.

Author's Changes to the Manuscript: We agree and have removed this reference and also modified the text to read (**P14, L383-389**): In the Fish Creek Watershed, most channels with small elliptical pools were located in the higher elevation areas associated with eolian sand and loess deposits compared to lower elevation marine sand and silt deposits. Whether this pattern relates to size and form of ice-wedge networks that develop in sandy soils or how eroding sandy soils moderate expansion by infilling pools or interactions with vegetation deserves further consideration. The other channel classes were more evenly distributed throughout the watershed and by surficial geology.

Comment from Referee:
Page: 16 "10 per 100 m" according to Fig. 3?

Author's Changes to the Manuscript: This has been corrected and thanks for catching this error.

Comment from Referee:
Page: 17 More useful to report ranges as for Q?

Author Response: We've actually decided to eliminate reporting discharge relative to slope and drainage area, because this was done during summer baseflows (as opposed to using a standard discharge such as bankfull). Plus only comparing slope and drainage area is simpler and more in line with other analyses of channel organization (now Fig 7 is one panel instead of two).

Comment from Referee:
Page: 18 "scars"?

Author's Changes to the Manuscript: Corrected and agree, these are typically very friendly landforms.

Comment from Referee:
Page: 19 "relatively deep and sinuous"? Quantify average values.
I agree with the general sense of these conclusions. But a 20% turnover of the beads in 60 years - on a geomorphic time scale - seems significant. In this same area, what would the turnover time be for a river reach; i.e., a full period from point bar to point bar? Is the beaded "transformation" relatively slower, faster, or similar. Also, were the 18% of pools that changed at the smaller, average, or larger size? What percentage of the total pool area is 10.8 m2 and 19.7 m2?

Author's Changes to the Manuscript: This is a good idea and we have added sinuosity here (**P16, L438-441**): It then flattens greatly to <0.01% over the last 5 km and becomes quite deep (exceeding 5 m in some pools) and very sinuous (2.3) with high, regular banks before its confluence with Fish Creek.

We understand the ambiguity in this paragraph and have revised this accordingly with the following clarifying statements (**P16, L457-457**): Thus our analysis suggests progressive expansion of these thermokarst landforms, yet the channel course appeared entirely unchanged over this period. (**P17, L489-492**): We suggest that beaded channels may evolve in a similar manner with most pools gradually expanding and some contracting with changing vegetation. Such behavior seems particularly apparent in viewing coalesced beads of some channels (Fig. 4c).

Comment from Referee:
This definition of a gulch (which is not a technical term?) should appear earlier in the manuscript and then would not have to be reported here. The sentence is awkward as is.
Author's Changes to the Manuscript: We think readers generally understand what "gulch" implies, but have added clarification in methods as well as referred to this area as the riparian zone instead (**P6, L170-172**): The channel gulch / riparian corridor was also delineated for both periods based primarily on the darker (greener) signature of taller sedges, willows, and dwarf birch and moister understory bryophyte communities.

Comment from Referee:
Page: 20 Confusing. Is "medium" intended to be a size designation here. The transition from "sand" to "sediment" is not helpful. Sand is a sediment. Is the transition from an "organic poor sand to an organic rich silt" (or peat)?

Author's Changes to the Manuscript: This section was not well written and we have gone thorough it to clarify all such issues (**P17, L496-517**): Analyzing the stratigraphy and geochronology of sediments in a large pool of Crea Creek may attests to the timing of stream channel formation and the depositional environment since initiation. A fibrous organic-rich layer with abundant terrestrial plant material separated the transition from organic-poor medium-grained sand to organic-rich silty sediment that is the uppermost unit—we interpreted this layer as basal sediments that were dated to 9.0 (±40), and 13.6 (±215) ka cal years BP (Fig. 10). The terrestrial macrofossils (shrub twigs) in this fibrous unit and the two dates that span 4 ka suggest this layer may have been a terrestrial soil that persisted for millennia on top of eolian or alluvial sand deposits, but predated the initiation of the beaded stream pool. Alternatively, this layer may represent the depositional environment of an early stage of the beaded stream pool where terrestrial vegetation was overhanging and being deposited, and adjacent soils were being eroded by ice wedge degradation and supplying a range of reworked material with different ^{14}C ages to be deposited onto this fibrous layer. Regardless, we interpret the 9.0 ka moss macrofossil sampled from the upper portion of the fibrous layer to be a conservative upper limit age on the initiation of the beaded stream pool. At this time, we do not know whether the lower limit of this age estimate is near the 9.0 ka time period, or represents the late Holocene. The large age-gap from 9.0 ka at 42 cm to ~0.7 ka at 22 cm suggests that either a water-level lowering event caused a hiatus of sedimentation through much of the Holocene, or that high flow events or other processes eroded the sediment deposits representing most of the Holocene (Fig. 10). However, there was no preserved wetland or terrestrial soil layer interrupting the *gyttja* unit, which would have accompanied a water-lowering event. The Crea beaded stream pool we examined appears to have had episodic sedimentation during the Holocene that is periodically eroded by either high flow events, or ice scouring.

Page: 30 Personally, I would switch the order of these last two paragraphs to more closely parallel the structure of the paper.

Author's Changes to the Manuscript: It took us some though, but in the end agree this it is better reversed and have done just this (**P26-27**).

Comment from Referee:
Figures Page: 44 The finer lines and shading in this figure are hard to see. Need to be bolder.

Author's Changes to the Manuscript: Thanks for noticing this and have improved quality of this and several other figures.

Comment from Referee:
Page: 50 It would be helpful to put the discharge below each date. This should be italicized and not bolded. Otherwise it could be interpreted as a missing panel C.

Author's Response: We ended up decided that this figure (now Fig. 14) was too complicated and only show data from mid-July and compare it now to an alluvial channel with similar discharge (all experimental data including Q are given in Table 3).

Comment from Referee:
Page: 51 Perhaps better to refer to the middle bead as having "cap" ice rather than "floating" ice. My guess is that the ice is pretty firmly attached to the edges and not really floating freely, as this suggests.

Author's Response: We get this, but floating ice refers to the presence of water under the ice and we think most readers familiar with Arctic systems recognize this and more so than cap ice. Plus we discuss floating ice in the text and if this is confusing to some readers, we think this will provide an explanation.

Response to BGD-11-C5894-2014

Comment of Referee:

General Comments:
This paper provides a significant improvement in the knowledge of the distribution and biophysical characteristics of beaded streams in the Arctic. As the authors describe, previous work on beaded streams is limited to only a few sites in the region around Toolik Lake, AK. The authors map the pan-Arctic distribution of beaded streams using Google Earth imagery and aerial surveys and relate the distribution to regional permafrost and geological characteristics. Three issues detract from their findings: 1) the extent of their survey of Google Earth imagery is unclear, 2) the impacts of changing resolution on the uncertainty of their results are not quantified, and 3) the locations described are obscure to general readers. These issues could be partially resolved with one or more maps with these pertinent details (specifying where snow-off images of sufficient resolution are available); better maps could also improve discussion of the focused surveys and measurements made in the Fish Creek watershed. Uncertainty could be presented based on a case study of areas that exhibit minimal change in features over time, but span the range of image resolution available for the pan-Arctic region.

Author's Response: We appreciate the reviewer's recognition of the significance of this work. The three main criticisms raised are all valid (and similar to those noted by another reviewer). Originally we did not present quantitative data on the Google Earth survey, which we now have and this allows the reader to understand how image resolution impacted our survey. We now report the percentage of high resolution snow-free imagery in Table 1 and use these data to estimate total beaded networks in these locations. We have also worked to clarify the place descriptions by adding full Alaska North Slope figure (Fig. 2, with physiographic and place names labeled) and also a separate Fish Creek watershed map (Fig. 3, with study sites labeled). We would like to show a pan-arctic map, but elected not to because it was very hard to show the locations of high resolution which typically occur in narrow sporadic bands and trying to show this in one map would be impossible to see (and many finer-scale maps would be far too much for a journal publication). Instead we think that presenting Table 1 along with example scenes from each country (Fig. 1) provides a clear and accurate representation of these data that readers can understand.

Author's Changes to the Manuscript: GE methods clarified as follows (**P3, L64-83**): The Circum-Arctic survey utilized imagery available in GE to identify channels with beaded morphology. This analysis focused on the continuous permafrost zone north of 66^{o} latitude. We utilized the historical image browser function in GE to access the highest resolution imagery (< 5-m) possible for a given region. This analysis focused on portions of Alaska (U.S.A.), Siberia (Russia), and northern Canada totaling approximately 4.5 million km^2. We found that most channels with beaded morphology could be identified when scanning images at 1:6,000 when the imagery was had a resolution of 5-m or finer and was mostly snow-free. The availability of high resolution, snow-free imagery in Alaska was quite good, covering 80% of the continuous permafrost zone surveyed. In Russia and Canada, the availability of such imagery was much lower, 11% and 9%, respectively, as of 2013 (Table 1). For this survey, zoomed in on each channel with beaded morphology for closer inspection and verification and marked its course at the furthest downstream point on the network of beaded channels. Surface elevation, latitude, and classes of permafrost ground ice were attributed to each point using thematic datasets for panarctic (Brown et al., 1998) and Alaska-focused permafrost and ground ice distribution (Jorgenson et al., 2008) and surface elevation. In order to compare among regions with differing extents of sufficient imagery, we extrapolated the number of surveyed streams based on the proportion of high resolution imagery available

to estimate the total number of beaded stream networks in the Circum-Arctic continuous permafrost zone (Table 1). We additionally estimated drainage density of beaded channels based on assuming an average network length of 10 km, which results in only a broad regional average and definitely varies considerable on finer scales.

Comment of Referee:

The authors present and evaluate hypotheses about beaded stream morphology and channel formation in the Fish Creek and Ublutuoch River watersheds in the results and discussion, but these hypotheses are not presented in the introduction section. This makes the results presented appear weaker. More context is needed for why Fish, Crea, and Blackfish sites are important and worth studying, and how they differ from most previous work. This is scattered throughout the manuscript, but it would be helpful to present the motivation and context for these sites early in the manuscript. Because the manuscript is already long, these revisions may require substantive revisions or rethinking the overall manuscript structure to ensure its accessibility to a broad audience.

Author's Response: We have added some additional context in the introduction and methods, as well as a map showing their location relative to other studies (Fig 2).

Author's Changes to the Manuscript: Modified text to set up work on ACP (Fish Creek) (**P2, L33-41**) In foothills watersheds, beaded streams are typically fed by linear hillslope water tracks (McNamara et al., 1999), while on the ACP these channels initiate mainly from thermokarst lakes and drained thermokarst lake basins (DTLBs) (Arp et al., 2012b; Whitman et al., 2011). Based on existing research, it is uncertain whether high densities of beaded streams exist beyond this long-standing focal site (Imnavait Creek / Toolik Lake) and this more recent studied watershed (Fish Creek). Newly published work from Russian permafrost zones is also expanding our knowledge of beaded stream distribution (Tarbeeva and Surkov, 2013). Still, an understanding of their formative processes and the broader watershed functions they provide are currently lacking.

Comment of Referee:

The thermal and hydrological data from the authors' monitoring efforts are clearly presented in general, but merit comparison with other systems, either in similar systems in the Arctic or temperate systems. The implications of the seasonal thermal and hydrological regimes in beaded streams that the authors describe for fish habitat and dispersal are compelling.

Author's Response: We agree that adding comparisons with other work is essential. We originally made comparison to the limited work in Imnavait Creek, but since submitting this paper have discovered a newly published work Tarbeeva and Surkov, 2013 on beaded stream in Russia. Though in a somewhat obscure journal, there was much information to draw upon of which we've added thorough out. We also made some additional comparisons to channel initiation in Imnaviat Creek **(P14, L397-400**), to long-term processes of other Arctic landforms (**P16, 459-464**), and to hydraulics of other Arctic streams and an alluvial stream (Fig 14, Table 3, **P24 L693-696**).

Comment of Referee:

Finally, there are numerous spelling, grammar, and sentence structure revisions

needed before the manuscript is published. All acronyms must be defined at first use.
Extra checks on figure and caption text would be warranted.
Specific Comments (page, line number):

Author's Response: Yes, we certainly agree and appreciate the time spent pointing these out.

Comment of Referee:

TITLE: Too general. Consider something more descriptive, like, "Distribution and biophysical processes of beaded streams in Arctic permafrost landscapes"

Author's Response: This is a better title and have decided to use this exactly. Thanks for this suggestion. We actually had something similar to this originally, but made it unfortunately too brief and general before submitting.

Comment of Referee:

ABSTRACT: captures the key points, but see general comments above.
INTRODUCTION: 11393, 10: no citations following ": : :limited to only one site." and then not discussed until the 3rd paragraph at line 21. Revise to help the reader follow what's been done and how your work fits in.

Author's Response: We have added this reference, but otherwise don't follow this comment. The second paragraph directly discusses previous work on beaded streams being exclusively in the foothills and suggests the need to expand to the coastal plain where they seem more common. If the reviewer was referring to something else, this is not clear.

Author's Changes to the Manuscript: Reference was added here (**P1, L8**).

Comment of Referee:

METHODS:
11395, 22-25: "All point locations for this survey..." This sentence is awkward and required rereading.

Author's Changes to the Manuscript: Agreed and this was reworded as (**P3, L73-76**): Prospect beaded channels recognized while scanning were inspected more closely (finer scale) to verify their form and the course was marked as the furthest downstream network point of continuous beaded channel.

Comment of Referee:

11396, 27: What does CIR stand for?
11396, 29: Source for the ifSAR DEM?
11397, 26: Is a gulch the same as a run? If so, use consistent terminology. I don't see any obvious gulches in the images of Figure 4.

Author's Response: A gulch is meant to be the incised terrain surround the active channel and we've clarified this by describing it as the riparian zone according to this text (**P6, L171-173**): The channel gulch / riparian corridor was also delineated for both periods based primarily on the darker (greener) signature of taller sedges, willows, and dwarf birch and moister understory bryophyte communities.

Author's Changes to the Manuscript: CIR and IfSAR DEM are now initially defined in the text (**P4, L108-114**): All perennial channels in the Fish Creek Watershed were delineated from 2002 mid-July color infrared (CIR) photography (2.5-m resolution) in a GIS environment. Streams with beaded morphology were quantified according pool density and size (measured as width perpendicular to the direction of flow) and valley gradient from a 5-m interferometric synthetic aperture radar (IfSAR) digital elevation model (DEM) at a segment scale, typically 1-3 km length that was representative of individual drainage networks.

Comment of Referee:

11398, 4-8: Clarify terminology here. Why are these importance for identifying alluvial transitions?

Author's Changes to the Manuscript: Good point and we've added additional clarification and a reference (**P5-6, L145-149**): Such local controls on delivery of new water and sediment to channels were expected to help explain changes in form downstream, similar in concept to mountain drainage networks flowing through lakes (Arp et al. 2007) and as hypothesized for Arctic drainage networks (Tarbeeva and Surkov, 2013).

Comment of Referee:

11398, 21-22: "...black and white to avoid visual bias." Would be helpful to revise and end sentence this way.

Author's Response:

Author's Changes to the Manuscript: Agreed and revised, though a bit differently than recommended (**P6, L163-165**): Manual analysis of both datasets was conducted in black and white to avoid any bias that may have arisen due to differences in film types and their separation by so many years of time.

Comment of Referee:

11398, 27-28: Can you explain this hypothesis further and integrate it into the beginning of this paragraph rather than halfway through? Also need to be explicit later about tying back to this hypothesis.

Author's Changes to the Manuscript: Yes, we have moved this sentence to the second in the paragraph, along with modifying the first sentence to flow into this hypothesis (**P6, L153-158**): To better understand the evolution of beaded channels we compared the position and morphology of one channel over a 64 year period using high resolution photography from 1948 (Black and White, Naval Arctic Research Laboratory (BW NARL)) and 2013 (color-infrared at 25-cm pixel size, Aerometric Inc) located in the Fish Creek Watershed. This was done to examine the hypothesis that beaded streams evolve in a manner similar to observed degradation of ice-wedge intersections, but lacking channel connectivity.

Comment of Referee:

11399, 13-18: These sentences should be rewritten so that they are more intelligible.

Author's Changes to the Manuscript: Rewritten as (**P7, L185-191**): Another core was collected from a pool in 2013 at nearby Blackfish Creek (Fig. 3) and macrofossils were collected from above several distinct sand horizons within the core. The plant macrofossils were prepared for analysis with an acid-base treatment and analyzed for ^{14}C content using standard acceleratory mass spectrometry techniques at the NOSAMS facility at Woods-Hole Oceanographic Institute. All radiocarbon dates were calibrated to calendar ages using the Intcal 13 curve (Reimer et al., 2013) and are reported as the mean and two-sigma ranges of the calibrated ages.

Comment of Referee:

11400, 5-6: Revise sentence structure.

Author's Changes to the Manuscript: Revised as (**P7-8, L200-204**): Stream gauging was conducted using autonomous pressure transducers (Onset U20-001-01) anchored to pool beds, which were corrected to local atmospheric pressure to measure water height. Stream discharge was measured using the velocity-area method with either a ACDP (Flowtracker™) or electromagnetic (Hach ™) velocity meter mounted to a top-setting wading rod.

Comment of Referee:

11400, 20-23: It seems to me there should be a sentence in here analogous to, "We assume that ratios X or greater indicate thermal stratification."

Author's Response:

Author's Changes to the Manuscript: This is a good point and changed to read (**P9, L239-241**): …stratification in pools assuming that a ratio of surface temperature to bed temperature >1.1 indicated stratification.

Comment of Referee:

11401, 11: Move this paragraph about residence times so that it is the second paragraph in this section. More citations are needed in this paragraph as well.

Author's Response: We agree that moving this paragraph up is better and added one additional reference (Zarnetske et al. 2007) because they also used RWT in Arctic beaded streams. If other reference are needed it should be suggested where and why.

Comment of Referee:

11401, 16: Not always conservative, see lit. Have you evaluated the degree of adsorption possible here?

Author's Response: This is true and we neglected this initially. Now we report sorption coefficients and % RWT recovered as well as clarifying the behavior and limitation of using RWT as a water tracer.

Author's Changes to the Manuscript: Expanded text is (**P8, L216-223**): Rhodamine WT (RWT), a pink fluorescent dye, was used as a water tracer because it can be detected at low concentrations and only small quantities are required to reach target concentrations, which is an important practical consideration for remote field sites. RWT has low biological reactivity, yet does sorb to organic matter and begins photodegrading after several days of sunlight exposure at low concentrations (Vasudevan et al., 2001). Thus, RWT is not truly conservative, however is widely use to characterize channel hydraulics and transient storage processes, including previous work in Arctic beaded streams (Zarnetske et al. 2007). (**P8, L229-231**): Percent RWT recovery averaged 81% with an average sorption coefficient (λ) of 1×10^{-5} used to account for this loss downstream.

Comment of Referee:

11401, 26-28: Revise sentence structure.

Author's Changes to the Manuscript: Revised as follows (**P9, L231-233**) Tracer breakthrough curve data was plotted as cumulative solute recovered downstream and converted to velocity distribution by dividing reach length by travel time.

Comment of Referee:

RESULTS AND DISCUSSION:
11402, 23-26: Need some quantitative analysis of the conjectures in these two sentences.

Author's Changes to the Manuscript: The addition of Table 1 addresses this issue.

Comment of Referee:

11402-11403: The geographic descriptions are difficult to follow without additional more detailed maps of these regions for those who are not intimately familiar with Arctic geography. Additionally, locations like Imnavait Creek are referenced multiple times but not included on the map, although Toolik Lake, which is mentioned once, is.

Author's Changes to the Manuscript: We have revised Fig. 1 (now Fig. 2 and with these places labeled) and added Fig 3 (Fish Creek Watershed). We have also simplified some of this description of Canada and Russia.

Comment of Referee:

11403, 1-2: What are the differences in the sizes of areas surveyed?

Author's Response: Now addressed with Table 1.

Comment of Referee:

11406, 8-9: Are they going to be identified later, or do you mean the overarching Fish Creek Watershed study and not this manuscript?

Author's Changes to the Manuscript: We have removed this sentence because no we don't identify these later.

Comment of Referee:

11406, 13-15: Again, a hypothesis that should be mentioned earlier.

Author's Changes to the Manuscript: We have reworded these sentences as follow (because we did not intend this to be considered our new hypothesis, rather a generally accepted concept of fluvial geomorphology) (**P14, L390-394**): Comparing channels of entire watershed by individual slope and drainage area helps understand how the larger drainage network is organized from channel initiation points (channel heads) to larger alluvial sand-bedded channels (Fig. 7). This slope-area relationship is consistent with patterns more universally observed across a wide range of drainage networks (Montgomery and Buffington, 1997; Montgomery and Dietrich, 1989; Whiting and Bradley, 1993).

Comment of Referee:

11406, 28-30: Figure 3 does not show these relationships, but a figure that does would be helpful for following along with the ideas in this paragraph.

Author's Changes to the Manuscript: We agree and now don't cite Fig. 3 (now Fig. 6) and have reworded this section to read (**P14, L384-389**): In the Fish Creek Watershed, most channels with small elliptical pools were located in the higher elevation areas associated with eolian sand and loess deposits compared to lower elevation marine sand and silt deposits. Whether this pattern relates to size and form of ice-wedge networks that develop in sandy soils or how eroding sandy soils moderate expansion by infilling pools or interactions with vegetation deserves further consideration. The other channel classes were more evenly distributed throughout the watershed and by surficial geology.

Comment of Referee:

11408, 10: Where is the Ublutuoch River? This should be on the study area figure along with Fish Creek, Imnavait Creek and Judy Creek that are mentioned earlier, and Crea Creek, discussed later.

Author's Changes to the Manuscript: Figure 2 and 3 have been modified to show these sites.

Comment of Referee:

11408, 24: Assuming you meant meander scars, not scares.

Author's Response: That's right! Thank for catching this.

Comment of Referee:

11408, 26: after(space)which

Author's Changes to the Manuscript: corrected.

Comment of Referee:

11410, 12: vaguely? I would say it "may attest..."

Author's Response:

Author's Changes to the Manuscript: Agree now reads (**P18, L496-498**): Analyzing the stratigraphy and geochronology of sediments in a large pool of Crea Creek may attests to the timing of stream channel formation and the depositional environment since initiation.

Comment of Referee:

11410, 16: What are the errors on these age estimates?

Author's Changes to the Manuscript: We have added error estimates to these ages now.

Comment of Referee:

11411, 22: "yielded less certain" not "gave dubious"? can you quantify this?

Author's Changes to the Manuscript: We have changed this as recommended and no I don't believe this can be quantified. This issue is that we don't know the exact source and process transporting this material to where we cored it, which I believe is always an uncertainty.

Comment of Referee:

11411, 24-27: "However..." incomplete sentence, and the next sentence requires rewriting.

Author's Changes to the Manuscript: Yes, this was poorly worded, now reads (**P19, L533-535**): …in the right situation however, pool sediments may record upstream watershed events such as lake drainage, as we think is preserved in the Blackfish Creek core.

Comment of Referee:

11413, 13-15: Sentence needs revising or could be removed.

Author's Changes to the Manuscript: We agree and removed it.

Comment of Referee:

11413, 16-18: still bed temperatures? Or reference to adjacent tundra/stream?

Author's Response:

Author's Changes to the Manuscript: Yes, this refers to bed temperatures and have specified this (**P20, L580-581**): Typically winter bed temperatures rapidly approach the zero-degree curtain and average winter temperatures (November to April) consistently average 0^{o}C (±0.1).

Comment of Referee:

11414, 1: Remove "also."
11415, 3: Remove "interesting" (also appears elsewhere).
11415, 14: characteristics

Author's Changes to the Manuscript: We have corrected each of these and thanks for noticing these problems.

Comment of Referee:

11415, 20-23: Run-on sentence.

Author's Response:

Author's Changes to the Manuscript: Yes, this has been modified as such (**P22, L635-640**): Similar to the development of stratification in Arctic lakes, stream pools tend to stratify starting in early July following snowmelt runoff and associated cold temperatures and turbulent mixing. An episodes of intense summer warming leading to stratification was clearly observed in pools at Crea and Blackfish creeks starting on 9-July 2013 when the surface water temperature rose rapidly from 8 to 16^{o}C over several days while beds warmed more slowly, albeit to differing degrees (Fig. 13).

Comment of Referee:

11416, 3-8: cite or show data; paragraph is extensive review of Heim 2014 – consider whether it's needed in this much detail

Author's Changes to the Manuscript: We've eliminated and condensed this section but still include information from this study because it clearly links these physical processes to biota, and now reads (**P23, L654-664**): These rapid changes in flow and temperature regimes may provide important cues to fish migrating along larger river courses fed by beaded streams. Arctic grayling (*Thymallus arcticus*) are known to seek habitats that warm most rapidly in the spring to spawn, and the quickly rising temperatures of beaded streams may contribute to their importance as spawning habitats (Heim. 2014). In fact, we often see individual fish migrating up beaded channels with water flowing over bedfast ice just prior to peakflows, when their dark bodies can be easily observed crossing the white ice surface. Tracking studies of Arctic grayling tagged in Crea Creek, show a rapid pulse of upstream migration into the system during and after peakflow (Heim, 2014). This early upstream migration may represent an adaption to maximize time spent in productive spawning habitats at the earliest possible time in order to provide a longer period of growth for offspring.

Comment of Referee:

11417, 24-26: need to demonstrate the in-channel storage assertion (and potentially move this sentence later in this section); is the argument that in-channel storage is so large that it must swamp hyporheic zone storage in most beaded streams? Need to be explicit about this with the data presented.

Author's Response: The argument is both that beads should swamp HZ storage, but also that without a groundwater system there is no HZ zone.

Author's Changes to the Manuscript: We've tried to make this more clear, now reads as (**P24, L680-690**): Because most beaded streams are set within a permafrost framework without interactions with groundwater systems, the development of hyporheic flow through bed material or banks is unlikely. Storage processes have been investigated in Imnavait Creek and adjacent beaded streams around Toolik Lake in Alaska where the glaciated setting and corresponding porous substrates, and known spring systems, may allow hyporheic storage to play a significant role in beaded stream hydrology (Merck et al., 2012; Zarnetske et al., 2007). Still we suggest that the characteristic large size and frequency of pools of beaded streams strongly dominates transient storage, even when groundwater systems are present allowing hyporheic exchange, which is probably rare in continuous permafrost zones of the ACP where surface-water interactions with ground-water are absent.

Comment of Referee:

11417, 27-30: more info on tracer tests needed: % recovery? transience of flow over measurement time period? Steady flow at any time with successful recovery?

Author's Changes to the Manuscript: We have added info on % recovery methods (**P8, L229-231**): Percent RWT recovery averaged 81% with an average sorption coefficient (λ) of 1×10^{-5} used to account for this loss downstream.

Comment of Referee:

11418, 13-17: How does this distribution of water velocities compare to other Arctic and more temperate systems of comparable size?

Author's Response: This is a really good question and made us realize we hadn't presented this data very well originally. So we now show cumulative tracer recovered and do this for two beaded streams with different morphology and compare it to an alluvial stream with similar slope and discharge (Fig. 14). I think this is much better and wish other BTC data from stream was presented in this way. But unfortunately the tracer data from other studies is usually summarized as storage terms (which we do as well for comparison), but are hard for people outside the field to understand. Thanks for this suggestion!

Comment of Referee:

11418, 29: Remove "importantly."
11419, 14: Ditto to above.

Author's Changes to the Manuscript: Agree and removed.

Comment of Referee:

11420, 12: “Increase: : :by 18-fold”: assume this is compared to lakes alone

Author’s Changes to the Manuscript: Yes, this is correct and added.

Comment of Referee:

CONCLUSIONS:
11420, 14-16: Perhaps rewrite as “The coupled biophysical processes of beaded stream systems that provide key ecosystem functionality are described conceptually in Fig. 13.”

Author’s Changes to the Manuscript: We have done this exactly (**P26, L763-764**).

Comment of Referee:

REFERENCES: ok
TABLES: ok
FIGURES:

Figure 1: It would be more helpful in the inset to show the regions where Google Earth imagery was of adequate resolution to delineate beaded streams, rather than showing regions of continuous and discontinuous permafrost, since almost 99% of beaded streams occurred on continuous permafrost. Also consider maintaining blue for water instead of land. Define all colors used in legend.
Figure 2: Need to define ice-content ranges here. Context for why Fish Creek should be presented here or earlier in text.
Figure 3. Crea and Blackfish should be discussed here or earlier in text. Reader should be directed to Figure 4 for definitions of morphological characteristics.
Figure 5: Would be good to put this in context of McNamara at al.’s 1999 geomorphic scaling study.
Figure 6: I would like to see the same scales for the axes of each site in order to better visually compare them.
Figure 8: It is unclear what Core A and Core B refer to, as this nomenclature are not used in the manuscript text. Include the Blackfish Creek core, and the location of samples taken for 14C analysis. In the manuscript text, it is said that there are photographs of the cores. I would like to see this addition to the figure if they clearly show the distinction between the three layers.
Figure 9: sites should be indicated in a detailed map, or summarized in supplemental table with GPS coordinates
Figure 10. clarify whether stratification ratio was calculated for 7/1-8/15 for the year specified, or was the max reported for the duration specified in the text
Figure 12: X-axis can be misleading. (e.g., earlier injections can be misperceived to have slower water velocities because values are presented from high to low). Also need to include the discharge (or discharge range) during the time of injection along with the date within the distributions.

Author's Response:
Fig 1 – We decide to remove this figure because as it was very misleading and now present data in a table. We attempted to show the high resolution imagery on a circumarctic map like this, but it was a total mess to look at. We have revised now as Fig. 2 to include ice content ranges

Fig 2 – We describe in caption why fish creek is relevant.

Fig 3 – Now this is Fig. 6 (and we refer to figure 3 (Fish Creek Watershed with these streams labeled) in caption.

Fig 5 – Now is Fig 7 (we discuss McNamara et al. 1999 in text now which was a good idea, but is outside range of plot because much stepper watertrack dominated landscape).

Fig. 6 – Now Fig. 8, we have done this now and think this is an improvement.

Fig. 8 – Now Fig. 10. I'm not sure why we did this originally. The only reason two cores were take was that a Russian peat corer can only collect 50 cm increments, so two were needed. We did core this very large bead on two separate occasion and the core stratigraphy was nearly equivalent. We collected the second set of cores because the first basal date was surprisingly old. We do have photos of these cores, but the quality do not lend them well to a journal figure. Done in low light on snowy cold day in late March.

Fig. 9 – Now Fig. 11. We have added these sites to Fig. 3.

Fig. 10 – Now Fig. 12. We clarified this as: Thermal regimes were characterized by mean annual temperatures at pool beds (A) and stratification ratios as the average ratio between the pool surface and bed during the period from July to mid-August in each year (B).

Fig 12. Now Fig. 14. Thanks to your suggestion we've redone this figure considerably including the X-axis.