ABSTRACT

The River Continuum Concept (RCC)(Vannote et al. 1980) applies theories of fluvial geomorphology to river ecology. Conceived as a biological analog to the energy equilibrium theory of the physical system, the RCC hypothesizes that a continuous gradient in physical conditions along the river should result in a continuum of ecology along the river. At river confluences there is a sudden increase in discharge and debris, and the river morphology must make adjustments to the sudden flux of materials. Thus confluences represent locations of sudden change in the gradient of physical conditions along the river, which in turn cause sudden changes in gradient of ecology along the river, contesting the continuous gradient proposed by the RCC. Future work must evaluate which confluences function as discontinuous steps in the gradient in ecology of the river, and which function as spikes in biodiversity, having no overall influence on a continuous gradient in the ecology of the river.

INTRODUCTION

In the 1960’s, geomorphologist Luna Leopold theorized that from the headwaters to the mouth, as discharge increases downstream, a river adjusts width, depth, velocity, slope, sediment load, and sediment debris size, to create a continuous gradient of physical conditions. In 1980, Vannote et al. proposed that this continuous gradient of physical conditions along a river elicits a continuous gradient of biota along the same river, a conceptual model they named the River Continuum Concept (RCC). The RCC hypothesized “that structural and functional characteristics of stream communities distributed along river gradients are selected to conform to the most probable position or mean state of the physical system”. Vannote et al. (1980) also believed that the physical structure of the river provided a “template” for riverine biologic processes and functions, and the gradual change in a river’s physical structure forces a gradual change in such ecosystem characteristics. Consequently, when traveling downstream from the
headwaters to the mouth of a river, the RCC proposes that a continuous change of physical conditions should force a similar longitudinal continuum in biota.

Many physical scientists (e.g. Montgomery 1999, Benda 2004) have challenged this “linear perspective” of riverine ecosystems (Benda 2004). They have suggested that locations of geomorphic and hydrologic disturbance in the form of tributary confluences, landslides, changing valley morphologies, etc., create discontinuities in the above mentioned physical “template”, consequently forcing patchy ecological habitat distributions. This chapter focuses on such disturbances, and more specifically on the question of how do tributaries and the associated interactions with mainstem rivers affect/influence this linear perspective proposed by the RCC? Or more precisely, how might tributary and mainstem interactions disrupt the perceived continuous longitudinal gradient in physical and biological structure within riverine settings?

Ultimately, the answer depends on the characteristics of the confluence. While early fluvial geomorphic theory provided an adequate physical model from which to build the RCC, subsequent research on the hydrogeomorphic effects of tributary confluences (e.g. Best 1986, Benda 2004) suggest that things may not be so simple. It will be shown that hydrologic and geometric attributes play a fundamental role in determining physical structures observed at channel confluences, and that variations in these attributes help determine whether confluences will appear as short-lived spikes in a large-scale, continuous gradient of geomorphic and ecological conditions, or whether changes affected by confluences will cause a stepwise change in longitudinal conditions, fundamentally creating a discontinuum at odds with the RCC. These end-member conceptual models will then be explored in the context of the Grande Ronde River, Oregon.

**Energy Equilibrium Theory**

Vannote et al.’s (1980) RCC is grounded in early fluvial geomorphologic theories developed by Luna Leopold and others (e.g. Leopold and Maddock 1953) during the 1950’s and 1960’s. Leopold and colleagues theorized that a river will “maximize the efficiency of energy utilization while using energy at a uniform rate,” and in doing so will form a continuous gradient in physical structure along the river (Vannote et al. 1980). Leopold’s theory of riverine energy conversion, utilization, and transport, is analogous to the concept of entropy in the field of thermodynamics. Entropy is the measure of energy in a system available for external work, and
the more entropy, the more energy is available for work (Leopold and Langbein 1964). Considering how this available energy might be distributed in a river system is the theoretical basis for the energy equilibrium theory.

Rivers are open physical systems, allowing transfer of energy and materials into and out of the fluvial environment. In this open system, water has potential energy at a given elevation and as it decreases in elevation it is converted to kinetic energy in the form of flowing water, and then dissipated as friction at the boundary, the boundary in the case of rivers being the river bed and banks (Leopold and Langbein 1964). According to Leopold (1964) the river maximizes its utilization of this available energy through the adjustment of eight interrelated variables: width, depth, velocity, slope, sediment load, size of sediment debris, hydraulic roughness, and discharge. This approach to understanding channel adjustment, commonly termed “hydraulic geometry” (Leopold and Maddock 1953), assumes that the mentioned variables will mutually adjust to changes in stream discharge (i.e. energy) (Leopold 1964). The result is a river exhibiting a continuous gradient of channel form variables and concave longitudinal profile in response to a downstream increase in discharge (Fig. 1a).

Leopold’s approach treats the adjustments made by the river’s physical structure as a continuous function of increasing downstream discharge (Richards 1980), as a consequence of additional flow supplied by tributaries (Leopold and Langbein 1964). However, it has been proposed that changes in the geomorphic channel structure could occur at tributary junctions (Richards 1980), locations at which there are dramatic changes in discharge and sediment loads that must force and adjustment by the interrelated channel form variables described by Leopold: width, depth, velocity, slope, sediment load, size of sediment debris, and hydraulic roughness. Therefore, according to the theory of energy equilibrium, sudden changes in physical conditions gradient of the river must occur at tributary junctions due to sudden increases in discharge and energy. Figure 1b illustrates sudden changes gradient in the various physical aspects of a river at tributary junctions.
HYDROGEO MORPHOLOGY OF TRIBUTARY CONFLUENCES

If sudden mainstem geomorphic changes do occur at tributary junctions due to a sudden influx of discharge and sediment from the tributary, how do these changes affect the continuous longitudinal gradient in physical structure that serves as the template for the RCC? Will a sudden change in physical structure at a tributary junction cause a permanent change in the river’s physical structure, in the form of a stepwise change, never rebounding to the physical structure the river exhibited just before the tributary junction? Or will the sudden change in physical structure be momentary, the river returning to the similar physical structure just prior to the tributary junction, allowing for a continuous gradient with only short-lived spikes in change? The answer to these questions will determine how tributary and mainstem interactions will affect the RCC. To further understand how change in river structure occurs at confluences, and whether
this change is in the form of spikes or steps, it is important to examine the physical dynamics of confluences. This begins with understanding the stream flow at tributary junctions.

Stream Flow Effects due to Tributary Junctions

The structure of mainstem stream flow goes through a very unique change at tributary junctions. Flow will decelerate before it enters the tributary junction. There is a highly turbulent mixing zone with upwelling as the mainstem and tributary combine. Finally there is an acceleration of flow as it travels downstream from the confluence.

Figure 2. Illustration of flow at tributary junctions. (from De Serres et al. 1999)

The sudden change in the structure of flow at confluences is caused by a region of highly turbulent mixing and upwelling of flow from the merging of two streams, as seen in Figure 2. If the main channel discharge is large enough to overpower the tributary channel discharge, reverse flow in the tributary can be observed (De Serres et al. 1999). Enough of the flow at the
confluence is not moving directly downstream thus causing a reduction in average stream velocity in the downstream direction. This reduction in average stream velocity can back up and reduce flow velocities upstream of the confluence. As flow begins to redirect downstream, collectively there is an increase in flow velocity just beyond the confluence.

In the downstream direction, momentary changes in physical structure will occur at confluences due to changes in flow structure at confluences. However, for changes in physical structure at confluences to remain as a permanent change in physical structure traveling downstream of the confluence, a substantial increase discharge from the combining of the tributary and mainstem flows is required. The permanence of the change in physical structure depends on the ratio of discharge of the tributary to the ratio of discharge of the mainstem (Benda et al. 2004). A large discharge ratio is due to a large tributary watershed. The larger the discharge ratio, the larger the sudden increase in discharge caused by the tributary, the more permanent changes in physical structure will be in the downstream direction due to the tributary. Still, despite the size of the discharge ratio, physical structure changes will occur at confluences due to the mere combining of two streams, creating morphology unique to all confluences.

The Fluvial Geomorphology at Tributary Junctions

Confluence morphology can generally be lumped into two shape types: symmetrical and asymmetrical (Fig. 3 and Fig. 4). At tributary junctions, the bed morphology is made up of three broad elements: avalanche faces at the mouth of the tributary, an area of scour in the center of the junction, and downstream bar formations (Best 1986). Scour is the removal of sediment from the bed, and bars are formed when sediment is deposited. For both asymmetrical and symmetrical confluences, avalanche slopes and central scour are in similar areas (Figs. 3 and 4). However, for asymmetrical confluences bar formation occurs at the downstream corner of the junction, while bar formations for the symmetrical confluence occur midstream below the central scour. There may also be additional bar formation on the downstream corners of the symmetrical confluence (Fig. 5). All three confluence bed morphology elements are a function of discharge ratio, confluence angle and sediment yield, illustrated in Figure 3 (Best 1986). Discharge ratio is the ratio of tributary discharge to mainstem discharge. Confluence angle, labeled as $\alpha$ in Figure 3, is the angle of the upstream tributary junction corner. And sediment
yield is the total sediment outflow from the tributary basin over a specified time period (Knighton 1998).

![Diagram](image)

**Figure 3.** Asymmetrical and symmetrical confluence structures. (Best 1986)

![Diagram](image)

**Figure 4.** Symmetrical confluence bar sediment deposition and scour. (Best 1986)
As a whole, tributaries represent areas of sudden change in channel bed morphology due to a significant increase in sediment load along the mainstem river. In fact, discontinuities in the fining of sediment are often observed at tributary junctions (Rice 1997). The amount of sediment deposition depends on the discharge ratio and sediment yield of the tributary. If the discharge of the mainstem is too large, it will flush any sediment introduced by the tributary downstream. If the discharge of the mainstem is not overpowering, and/or the tributary has a high sediment yield, large amounts of sediment can be deposited at the confluence, possibly forming an alluvial fan. All tributaries experience some degree of sediment deposition causing some change in sediment texture of the mainstem at confluences.

Sediment enters the mainstem by three main processes: normal runoff transporting bed load sediment and suspended load sediment; flash floods that transport high amounts of sediment; and debris flows. Suspended sediment is sediment that is transported while remaining entrained in the flow. Bed load sediment is sediment that is transported along the bed often as a collective sediment formation (e.g. dunes). Normal runoff can transport low amounts of sediment from the hill slopes, move it down stream as either suspended sediment or bed load sediment, which can be eventually deposited at the tributary junction due to the lower velocities experienced at confluences. Flash floods, transport sediment in a similar fashion as normal runoff, except that due to the higher magnitude of flow, flash floods have a larger capacity for transport sediment, and therefore tend to deposit more sediment of larger size than normal runoff. Debris flows have the highest capacity for sediment transport and deposition. A debris flow is a flowing mass of water, sediment, organic matter often caused by flash flooding and/or
land sliding. A debris fan may form at the mouth of a tributary experiencing a debris flow due to the large amount of sediment combined with a reduction in flow velocity at the tributary junction.

In general, the mainstem experiences a sudden increase in sediment load at confluences due to tributary input. This sudden input of sediment from the tributary has the potential to dramatically change the overall channel profile of the mainstem at confluences (Fig. 6). Deposition of sediment can be sufficient to cause a sudden reduction in slope at the confluence which in turn increases slope just downstream of the tributary junction. The reduction in slope at tributary junctions can then increase pool depth and increase channel width (Benda et al. 2004). Increasing channel width increases lateral connectivity; this is because a reduction in flow velocity at confluence causes water to push further up onto the banks of the mainstem increasing connectivity to the flood plain as shown in Figure 6 (Benda et al. 2004). By having increased floodplain connectivity at confluences, not only can tributaries affect downstream aquatic changes, but also can affect downstream terrestrial changes, causing the river to experience an overall change at the confluence.

Figure 6. Planform and longitudinal profile of confluence morphological effects. (Benda et al. 2004)
Confluences as Physical Change in the Downstream Direction

Due to the influence of tributary junctions, it is not accurate to describe the physical structure of the mainstem stream as a “smooth monotonic function of distance” (Ferguson 2006). As shown, tributary junctions represent areas of dramatic changes in physical conditions along river. Whether physical change at confluences are seen as spikes in the physical gradient or steps in the physical gradient depends on a number of key factors: basin discharge, basin size, sediment yield, network pattern and basin shape, drainage density, spatial distribution, and local geometry (Benda et al. 2004).

Discharge of the mainstem abruptly increases at confluences due to the influence of tributaries, and must be accommodated for by adjustments in interrelated channel form variables: width, depth, velocity, slope, sediment load, size of sediment debris, and hydraulic roughness (hydraulic geometry). Such adjustments translate sudden increase in discharge into sudden changes in channel and floodplain geomorphology at confluences. The larger the tributary discharge as compared to the mainstem discharge, the more sudden the increase in discharge will be, and the more permanent the change that occurs at confluences (Benda et al. 2004). This ratio in discharge between the tributary and mainstem plays a significant role in whether change in physical structure of the mainstem river occurring at confluences is in the form of spike or step. Large tributary discharge to mainstem discharge ratios are the most likely cause of a step change in physical gradient due to the required adjustments hydraulic geometry.

Additionally, it has been found that fluvial geomorphic adjustments in hydraulic geometry occur at tributary junctions with tributary basin area to mainstem basin area ratios that approach 0.6 to 0.7 (Rhoads 1987). Additionally, Benda et al. (2004) showed a threshold in which tributaries with basin areas less than 0.4 square miles do not have observable significant morphological affects on mainstem rivers with basin areas larger than 20 square miles. In general, tributaries of lower flow magnitude in comparison to the mainstem stream have less significant of a morphological effect on the mainstem, and less of an effect on the downstream physical gradient.

This does not mean basins of small areas should be discounted. Mass sediment transport, often in the form of debris flows, generally comes from small drainage basins. Drainage basins with high relief elevation to channel length (relief ratio) typically have small basin areas, and yield high amounts of sediment. The reason such basins yield high amounts of sediment is
because with high relief ratio comes steeper slopes and more occurrence of mass wasting processes, like landsliding. These processes deliver larger amounts of sediment to the tributary to be moved downstream to the confluence. Therefore small tributary basins, due to high sediment yields, have the potential to cause significant geomorphic change at confluences.

Sediment yield is an important factor in geomorphic change at confluences. The amount sediment coming out of a tributary and the size distribution of the sediment will influence the planform shape of the main channel, slope of the channel, and the grain size distribution at the confluence. The more sediment yielded from a tributary the greater affect it has on physical change of the mainstem river. However, sediment fining effects from tributary inputs are generally observed at the $10^0$ to $10^2$ km scale, and at scales of $10^3$ to $10^4$ km a consistent sediment fining gradient re-emerges (Rice 1998). This means typically, sudden changes in sediment texture due to tributaries are short lived spikes, with sediment texture quickly recovering to a continuous longitudinal gradient in sediment texture, having no effect on the overall downstream continuous gradient of physical conditions.

Since tributary stream discharge and basin area are factors, so are the roles river network pattern and basin shape (Benda et al. 2004) play in determining hydrogeomorphic impacts of tributaries. Channel networks that are trellis patterned (rectangular shape) tend to have a larger number of lower stream sizes relative to the mainstem. Despite an increase in discharge in the mainstem in the downstream direction, there is no appreciable increase in the relative size or discharge of the tributaries in the downstream direction. Therefore, trellis pattern river networks tend to see less downstream changes due to confluences, and thus act as spikes in perceived longitudinal gradients. On the other hand, dendritic network patterns (heart shaped and pear shaped) have tributaries that increase in stream size (and thus discharge) in the downstream direction. Consequently, such networks will see more change in physical structure at confluences, and thus may potentially act as stepwise changes in perceived longitudinal gradients in physical conditions (Benda et al. 2004).
Drainage density and spatial distribution can also affect the magnitude of geomorphic heterogeneity at confluences. The larger the drainage density, the more tributary junctions that exist, the more possibility for departure from the average channel gradient at confluences. Also spatial distribution has lumping effects in the longitudinal direction. Features like canyons can cause tributaries to be lumped together, leading to overlapping effects of confluences on channel morphology. In such a situation, the tributaries become concentrated, and land forming increases, causing an overall increase in physical change at tributary junctions. Typically the confluences that have tributaries affecting the physical structure of the main channel the most are those located in the middle of the drainage network. This is a large scale lumping effect; therefore, steps in change are more likely to occur in middle of the drainage network.

Morphologic effects due to confluences are also linked to the local geometry of the river network. As has been previously discussed, the angle at which the tributary enters the mainstem plays a role in the morphology at a confluence. While angles of intersection almost always are acute (less than 90°), as the tributary-mainstem intersections approach 90°, the tributary tends to have more of an influence on the bed morphology of the mainstem river (Benda et al. 2004). Also as previously covered, bar location and size, along scour depth depend on the confluence angle. Confluences with angles greater than 70° are more likely to form debris fans, while at more acute angles deposition is less pronounced. Confluence angle can have a significant effect on change at a tributary junction, but will have less significant of an effect compared to other factors such as discharge ratio on downstream change, and therefore less likely to influence whether change at a confluence is a step or spike.
Confluences and the River Continuum Concept

As shown, tributary junctions create significant changes in the physical structure along the river. Water, sediment, and woody debris drastically increase at tributary junctions. Such increases facilitate marked changes in the main channel morphology at tributary junctions. The RCC states that a river’s continuous gradient in physical structure along the river elicits a continuous gradient in riverine ecology form and process. Strictly conforming to the concept that the physical structure serves as a template to the biologic structure, sudden change in the gradient of morphology translates to sudden change in the gradient in ecology. For weaker (smaller) tributaries, with lower discharges and sediment yield relative to the main channel, any changes to the mainstem channel physical structure affected by tributary inputs will momentarily appear as spikes in physical structure, and therefore momentary spikes in biodiversity. Such tributaries will have no significant influence on the overall continuous change in biota along the river and thus conform to the RCC. However, for strong influential tributaries, morphologic
changes affected by tributary inputs can force steps in the longitudinal gradient of physical and ecological riverine forms and processes, and as a result deviate from the continuum of the RCC. Overall, tributary junctions represent biologic hotspots along the main channel of a river (Benda et al. 2004). Changes in channel width and depth, bed substrate, wood storage, and water velocity occurring at confluences should enhance total species richness of macroinvertebrates (Benda et al. 2004). Increased wood storage and pool formation at confluences promote fish rearing habitat (Benda et al 2004). In the summer time, cooler tributary waters can function as a thermal refuge for heat stressed fish (Ebersole et al. 2001). Greater variation in floodplains and terraces at tributary junctions due to higher lateral connectivity, increases suitable substrate for riparian communities, and promotes increased plant diversity. Tributaries also tend to be more shaded, limiting primary production and uptake of nutrients (Kiffney et al. 2006). Consequently tributaries are a large source of nutrients to nutrient depleted mainstems.

As shown, tributaries cause change in the mainstem physical structure in the downstream direction, and therefore change in biologic structure in the downstream direction. A tributary may force a step in biologic structure of the mainstem, in which the biologic structure never recovers to the state just prior to the tributary, suggesting continuum in biologic structure does not exist and the RCC fails. However, a tributary may force a change in the mainstem that is merely a spike in biologic structures, allowing the biologic structure to return to the state it was in just prior to the introduction of the tributary. In this case it is possible the tributary will have no overall affect on a biologic continuum of the mainstem river and the RCC holds at a larger scale. Ultimately, whether the RCC stands up at a tributary junction depends on the tributary characteristics previously reviewed.

**CONFLUENCE EFFECTS AND THE GRANDE RONDE RIVER**

In the context of the Grande Ronde River, which confluences would function as spikes in physical structure, having no overall influence on a continuous gradient in the physical structure of the river, and which confluences act as discontinuous steps in the gradient in physical structure of the river? As mentioned the answer to this question is highly dependent on such key factors as: basin discharge, basin size, sediment yield, network pattern and basin shape, drainage density, spatial distribution, and local geometry. This question will be answered by analyzing, under the aforementioned factors, several confluences of the Grande Ronde River: Catherine
Creek, Joseph Creek, Sickfoot Creek, Wildcat Creek, Courtney Creek, Bear Creek, the Wenaha River, the Minam River and the Wallowa River (Fig. 8). This analysis will begin with the less influential factors working up to the more influential factors.

Figure 8. Locations of tributary junctions in the Grande Ronde Basin analyzed. (Nowak 2001)
Drainage Density, Network Pattern, and Basin Shape

The entire Grande Ronde basin, including the tributaries listed, would be characterized as a pear-shaped, dendritic network with a high drainage density. Dendritic networks have a large number of tributaries with a variety of basin sizes and flow magnitudes as compared to trellis network basins. This means in the Grande Ronde basin, it is probable there exists a tributary capable of causing physical gradient change in the form of a step rather than a spike.

Local Geometry

The most acute confluence angles between the aforementioned tributaries and the Grande Ronde River are found at the Wallowa River, Wenaha River, and Joseph Creek confluences. As expected there are no alluvial fan formations at the mouth of these rivers, but there is extensive downstream bar formations occurring below these confluences. The smaller basin streams: Sickfoot Creek, Wildcat Creek, Courtney Creek, and Bear Creek all are less acute, and have alluvial fan formations at the mouth of these streams. The Minam River also appears to be less acute, yet there is no evidence of alluvial fan formation. It is important to note, local geometry does not indicate much about the possibility in step change for these confluences, but it does indicate that for the less acute tributaries there will be significant local physical change, but likely in the form of spikes, having no overall affect on a continuous gradient in physical structure.

Spatial Distribution

Portions of the Grande Ronde are entombed in canyons, causing lumping of tributary junctions. Courtney Creek, Bear Creek and the Wenaha River could be an example of lumped tributaries. Lumping effects may be present at these confluences, allowing these tributaries to cause a possible combined step in change, causing a discontinuous gradient in physical structure.
**Sediment Yield**

Sediment yield is a very important factor that can play a significant role in whether a tributary will influence the mainstem. From aerial photos and topographic maps, it appears both Sickfoot Creek and Wildcat Creek have steep hill slopes to the stream with scarce vegetation. This lack of vegetation cover and steep hill slopes produce more sediment from the hill slopes to the stream, which is then transported by the tributary downstream. The sediment transported is then deposited at the mouth of the tributary, forming debris fans that extend out into the main channel which can have an effect on physical structure change at the confluence. From aerial photos, it appears that the tributaries Sickfoot Creek and Wildcat Creek are forming debris fans that are pushing out into the mainstem Grand Ronde. However such changes in physical structure would merely be local to the confluence, and function as spikes in the overall physical gradient.

In general, a tributary with a high relief to stream length ratio can produce large amounts of sediment. Tributaries derived from the Wallowa Mountains have a higher relief than those from the Blue Mountains. It could then be expected that tributaries from the Wallowa Mountains (river right) of the same size as tributaries from the Blue Mountains (river left) would yield larger amounts of sediment, and therefore have a larger impact on change in physical structure.

**Basin Area**

The basin areas of Catherine Creek and Joseph Creek are 105 and 280 square miles, respectively, both under one-tenth the size of the mainstem (the Grande Ronde) basin area. Catherine Creek and Joseph Creek basin area ratios do not distinguish them as geomorphically significant, making their confluence with the Grande Ronde most likely a spike in gradient, with no overall disruption in the continuous gradient in physical structure.

According the USGS gauging station data the Wallowa River basin covers 950 square miles, with the total basin area of the Grande Ronde River just below the Wallowa tributary junction as 2555 square miles. That means the Grande Ronde River basin area excluding the Wallowa River of 1605 square miles. That gives the Wallowa tributary junction a tributary to mainstem basin area ratio of about 0.6, making it predictably a geomorphically significant confluence. The Wallowa River just below the Minam tributary junction has a basin area of 880 square miles. The basin area of the Minam River at the tributary junction is 240 square miles.
and the basin area of the Wallowa River excluding the Minam River basin area is 640 square miles. That gives the Minam tributary junction a tributary to mainstem basin area ratio of about 0.4, below that which would be predicted to be geomorphically significant. Therefore the two confluences, the Minam/Wallowa confluence and Wallowa/Grande Ronde confluence, would possibly experience a discontinuous, step-change in physical structure.

**Basin Discharge**

Both the Minam/Wallowa and Wallowa/Grande Ronde confluences will undoubtedly undergo change in physical gradient. However, the permanence of change (indicating step or spike) will ultimately depend on tributary and mainstem discharge ratios. The mean June discharge for the Wallowa River just below Wallowa is 1580 cfs which is met by the Minam River just downstream with a mean June discharge of 1540 cfs. Combining these two flows, would double the mainstem discharge (discharge ratio of ~2), which could cause significant changes in the downstream direction due to the required adjustments in hydraulic geometry. Such adjustments could translate into permanent step changes in physical structure in the downstream gradient, causing a disruption in the RCC at the Minam/Wallowa confluence. Even possibly more disruptive is the Wallowa/Grande Ronde confluence. Just below the Wallowa/Grande Ronde confluence, the mean June discharge according to USGS gauging stations is 4700 cfs. If both the Minam River and Wallowa River flows are combing to more than 3100 cfs at the Minam/Wallowa River, making flow in the Grande Ronde at most 1600 cfs, at a minimum in June, flow of the Grande Ronde is tripling at the Wallowa/Grande Ronde confluence (discharge ratio of ~2). This sudden increase in discharge would require significant adjustments in hydraulic geometry of the Grande Ronde from above the confluence to below the confluence. This would translate to significant and permanent changes in physical structure of the mainstem river from above the confluence to below the confluence. Consequently, both confluences would likely undergo a discontinuous stepwise change in gradient due to required adjustments in hydraulic geometry to a substantial increase in discharge.

**CONCLUSION**

The River Continuum Concept (RCC) proposes that a continuous gradient in physical conditions along the river, elicits a continuous gradient in biological conditions along the river.
As discharge of the river increases in the downstream direction, the river must adjust its physical conditions per the energy equilibrium theory (Leopold and Langbein 1964). A continuous gradient in physical conditions comes from the assumption that discharge increase is continuous. However, as discussed, at tributaries there is a sudden increase in discharge and sediment supply. Thus applying the idea that a sudden increase in discharge to the concept that the river adjusts its physical conditions with an increase in discharge, it should be expected that there would be dramatic changes occurring at confluences, and possible shifts in the longitudinal physical condition of the river. This would in essence create a either spikes or steps in the gradient in physical conditions. Applied in a similar fashion as the RCC, theses spikes or steps in physical conditions would create spikes or steps in biologic conditions. The question is which is it, spike or step in conditions. This inevitably would depend on variables such as basin discharge, basin size, sediment yield, network pattern and basin shape, drainage density, spatial distribution, and local geometry. Given the right conditions confluences could either serve as a spikes in change in conditions of the river, having no overall affect on the downstream gradient, validating the RCC, or serve steps in change in conditions of the river, causing a discontinuous gradient, disproving the RCC. Confluences like the Minam/Wallowa confluence and Wallowa/Grande Ronde confluence, with large basin discharge and area ratios would experience steps in change, causing a discontinuous gradient in conditions of the mainstem Grande Ronde River, questioning the validity of the RCC. However, most other confluences like Sickfoot Creek/Grande Ronde confluence and Wildcat Creek/Grande Ronde confluence, while they would experience significant spikes in change in the vicinity of the confluence, they would have no overall effect on the continuous gradient of river conditions, thus validating the RCC.
REFERENCES


