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REGIONAL AND GLOBAL PATTERNS IN CARBON EXPORT FROM LAND TO WATER

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PATRONS RÉGIONAUX ET MONDIAUX DE L'EXPORTATION DE CARBONE DE LA TERRE À L'EAU

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COMME EXIGENCE PARTIELLE
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ABBREVIATIONS AND ACRONYMS

BIC	Bayesian Information Criterion
BSI	Basin shape index
CarBBAS	Carbon Biogeochemistry in Boreal Aquatic systems
CH_4	Methane
CID	Carbone inorganique dissous
CO_2	Carbon dioxide
COD	Carbone organique dissous
DIC	Dissolved inorganic carbon
DOC	Dissolved organic carbon
ETC	Exports totaux de carbone
GES	Gaz à effet de serre
GHG	Greenhouse gases
PIC	Particulate inorganic carbon
POC	Particulate organic carbon
Pg	Petagram
TC	Total carbon
TIC	Total inorganic carbon
TOC	Total inorganic carbon

ABSTRACT

Carbon exported from terrestrial ecosystems to river systems is a critical component of the global carbon cycle. How much carbon is exported from watersheds, in what form, and when the exports occur, as well as the future response of riverine carbon export to climatic change driven naturally and anthropogenically, are major issues of biogeochemistry. However, few studies in the past simultaneously explored riverine carbon exported in different forms and thus we still do not have an integrated perspective of magnitude and regulation of total riverine carbon export at the regional and global scales. The research presented in this dissertation aims to explore the composition and drivers of total carbon export from land to rivers, from watersheds to northern regions to the global scale, and to identify the natural and anthropogenic controls on the global riverine carbon export to the oceans in the context of climatic change. In the thesis project, we used the data collected by the CarBBAS group over the past 5 years from 127 rivers and streams in Quebec, and have combined these with a newly collated global data set of published carbon concentrations and/or exports for 566 rivers draining a total of 74% of global exorheic area.

We first explored the influence of topography and land cover on the combined inorganic and organic carbon export from temperate catchments in southern Québec (Chapter 1). Our results show that whereas both are primarily driven by regional runoff, topography is slightly more important than land cover in explaining the variance in DIC export across watersheds, whereas land cover is much more important than topography in determining DOC export. The inter-annual differences in C export are driven mostly by shifts in annual precipitation and regional runoff. Further, the proportion of the catchment covered by natural vegetation had a negative effect on DIC export but a positive effect on DOC export, suggesting that a change in land cover that reduces vegetation (e.g. deforestation) would lead to modest decreases in TC export, but large increases in the DIC/DOC export ratio. As a follow up of these studies in temperate regions, we further quantified river-mediated export of dissolved organic and inorganic C (DOC and DIC), as well as the integrated aquatic emissions of both CO_2 and CH_4, from 44 boreal catchments that range widely in size, topography and land cover (Chapter 2). The resulting total C export was seasonally very variable, driven mostly by the annual runoff cycle, and averaged 15.5±5.3 g C m^{-2} (watershed) yr^{-1}. DOC dominated, on average, this total C export over the annual cycle (58%), but aquatic CO_2 emissions were a major component of export in all catchments (average 20%). Our results confirm that DOC and DIC exports are mostly driven by runoff but further regulated by fundamentally different environmental

factors, and that wetlands are a major source of DOC exported to rivers, but further demonstrate that lakes within the catchment are a strong DOC sink, such that the net export of DOC results from the balance between the two. The total annual C exported via rivers is within the range of net ecosystem production, and has the potential to fundamentally alter our perception of the role of these boreal landscapes as sources or sinks of atmospheric CO_2.

The meta-analysis of global riverine carbon export to the oceans has shown that beyond the expected hydrologic control over material flow, DOC export is mostly driven by a combination of natural variables, such the extent of wetlands and the average organic carbon content of the catchment soils, as well as by anthropogenic alterations of the landscape, such as the extent of croplands and, to a lesser degree, the presence or large reservoirs. In contrast, DIC export was mainly controlled by the extent of carbonate rocks (positive) and of water bodies (negative). In addition, the extent of cropland explained a substantial amount of variability. These models were then used to estimate carbon export for all exorheic watersheds not present in our database to derive a new global estimate of carbon export to the oceans of 0.68±0.05 Pg yr^{-1}, a substantial revision of the often-cited value of 0.9 Pg yr^{-1}. A retrospective analysis suggests that as much as 40% of the current C export is associated with the extent of agriculture on the planet.

In conclusion, this thesis has shown that in different landscapes and at different spatial scales, carbon export is driven by a combination of natural features of the landscape and human activities. It also highlights the differential regulation of the inorganic and organic fractions of C export. Anthropogenic impacts due to land use/cover change may be replacing the natural driving forces as the primary determinants of the magnitude and composition of both current and future transfers of carbon from land, through the hydrologic network, and ultimately reaching to sea, implying the importance of land use and management in controlling riverine carbon export from terrestrial ecosystems in the context of human-induced environmental changes, both regionally and globally.

Key words: river carbon export; carbon cycle; greenhouse gases (GHG); dissolved organic carbon; dissolved inorganic carbon.

RÉSUMÉ

L'exportation du carbone (C) des écosystèmes terrestres vers les systèmes fluviaux est une composante fondamentale du cycle global du carbone. Combien de carbone est exporté des bassins versants, sous quelle forme, quand les exportations se produisent-elles et qu'elle sera la réponse de l'exportation du carbone riverain face aux changements climatiques naturels et anthropiques sont toutes des questions biogéochimiques d'intérêt majeur. Peu d'études cependant ont explorées simultanément l'exportation des différentes formes du carbone riverain et nous ne disposons donc pas encore une perspective intégrée de la magnitude et du contrôle des exportations totales de carbone fluviale à l'échelle régionale et globale. La recherche présentée dans cette thèse vise à explorer la composition et les facteurs qui contrôlent l'exportation totale de carbone des rivières, des bassins versants des régions nordiques jusqu'à l'échelle globale et d'identifier les contrôles naturels et anthropiques de l'exportation de carbone fluviale globale vers les océans le contexte des changements climatiques. Dans cette thèse, nous avons utilisé les données recueillies par le groupe CarBBAS au cours des cinq dernières années provenant de 127 rivières et ruisseaux au Québec combinées avec un ensemble nouvellement rassemblées de données mondiales publiées des concentrations et/ou des exportations de carbone de 566 rivières drainant un total de 74% de la superficie exoréique mondiale.

Nous avons d'abord exploré l'influence de la topographie et la couverture terrestre sur l'exportation combinée de carbone inorganique et organique provenant de bassins versants tempérées du sud du Québec (chapitre 1). Nos résultats montrent que la topographie est plus importante que la couverture terrestre pour expliquer la variabilité du carbone inorganique dissous (CID) exportée des bassins versants, bien que les deux soient essentiellement contrôlées par le ruissellement régional, alors que la couverture terrestre est beaucoup plus importante que la topographie dans la détermination de l'exportation de carbone organique dissous (COD). Les différences interannuelles de l'exportation du C sont principalement régies par des changements dans les précipitations annuelles et le ruissellement régional. De plus, la proportion du bassin versant couvert par la végétation naturelle a eu un effet négatif sur l'exportation du CID, mais un effet positif sur l'exportation du COD, ce qui suggère qu'un changement de la couverture terrestre qui diminue la végétation (par exemple, la déforestation) conduirait à des diminutions modérées de l'exportation du C total, mais de fortes augmentations du ratio CID/COD des exportations. Pour poursuivre cette étude dans les régions tempérées, nous avons quantifié en outre l'exportation par

les rivières du COD et CID, ainsi que les émissions aquatiques de CO_2 et de CH_4 de 44 bassins versants boréaux de différentes tailles, topographie et de couvertures terrestres (chapitre 2). L'exportation de C total était très variable entre les saisons et notamment contrôlé par le cycle annuel du ruissellement, avec une moyenne de 15.5±5.3 g C m^{-2} (bassin versant) an^{-1}. Le COD domine en moyenne cette exportation totale de C sur un cycle annuel (58%), mais les émissions de CO_2 aquatiques étaient une composante majeure de l'exportation dans tous les bassins versants (moyenne 20%). Nos résultats confirment que les exportations de COD et CID sont principalement contrôlés par les eaux de ruissellement, mais aussi par des facteurs environnementaux fondamentalement différents et que les zones humides sont une source majeure de COD exportés vers les rivières. Nos résultats démontrent aussi que les lacs situés dans le bassin versant constituent un puits de COD, de telle sorte que l'exportation nette de COD résulte de l'équilibre entre les deux. Le C total exporté annuellement par les rivières est comparable à la production nette de l'écosystème et a le potentiel de modifier fondamentalement notre perception du rôle des paysages boréaux comme sources ou puits de CO_2 atmosphérique.

La méta-analyse des exportations fluviales globales de carbone vers les océans a montré qu'au-delà du contrôle hydrologique attendue sur le transport de la matière, l'exportation du COD est principalement entraîné par une combinaison de variables naturelles, tels l'étendue des zones humides et de la teneur en carbone organique moyenne des sols du bassin versant, ainsi que par des modifications anthropiques du paysage, tels que l'étendue des terres cultivées et, dans une moindre mesure, de la présence de grands réservoirs. En revanche, l'exportation de CID est principalement contrôlée par l'étendue de roches carbonatées (positif) et des plans d'eau (négatif). De plus, l'étendue de terres cultivées expliquait une quantité importante de variabilité. Ces modèles ont ensuite été utilisées pour estimer l'exportation de carbone pour tous les bassins exoréiques absents de notre base de données pour établir une nouvelle estimation globale de l'exportation de carbone vers les océans de 0.68±0.05 Pg an^{-1}, une révision substantielle de la valeur souvent citée de 0.9 Pg an^{-1}. Une analyse rétrospective suggère que jusqu'à 40% de l'exportation actuelle est associée à l'étendue de l'agriculture sur la planète.

En conclusion, cette thèse a montré que, dans des paysages différents et à différentes échelles spatiales, l'exportation de carbone est entraîné par une combinaison des caractéristiques naturelles du paysage et les activités humaines. Elle souligne également la régulation différentielle de l'exportation des fractions organiques et inorganiques du C. Les impacts anthropogéniques en raison des changements de l'utilisation des terres et des couvertures terrestres peuvent remplacer les pressions

naturelles comme principaux déterminants de l'ampleur et la composition des transferts actuels et futurs de carbone provenant de la terre, par le réseau hydrologique pour finalement atteindre la mer. Cela implique l'importance de l'utilisation et de la gestion des terres dans le contrôle de l'exportation de carbone riveraines des écosystèmes terrestresde dans le contexte des changements environnementaux induits par l'homme, régionalement et mondialement.

Mots clés: exportation de carbone, cycle du carbone, gaz à effet de serre (GES), carbone organique dissous, carbone inorganique dissous

INTRODUCTION

0.1 The role and importance of river system in carbon cycling

Carbon, as the building block of life, plays an important role in a series of processes that provide food, clothing and fuel for us, and thus we are unavoidably entwined with its biogeochemical cycle. Particularly in the past 50 years, human activity has gradually become a crucial driving force in global warming due to the anthropogenic impacts on regional and global carbon cycling (Vitousek et al., 1997; Ver et al., 1999). Actually, carbon cycling has been widely regarded as the key to our understanding of the earth surface system and global environmental change (e.g. climate change, land degradation and biodiversity loss) because it acts as an essential component linking abiotic to biotic components of the earth system through photosynthesis and decomposition, and also regulates biogeochemical cycling of other elements (e.g. N, P, S) (Himes, 1997; Chameides and Perdue, 1997; Falkowski et al., 2000; Heimann & Reichstein, 2008).

To date, numerous studies have focused on terrestrial and/or aquatic carbon cycle from different perspectives using various approaches and methods, aiming to have a better understanding of what are driving the coupling between global change and carbon cycling, how it is controlled or influenced naturally and anthropogenically, and the future response of terrestrial and aquatic ecosystems to it (e.g. Cao and Woodward, 1998; Cox *et al.* 2000; Betts, 2000; Feeman et al., 2004; Callaghan et al., 2010; Grosse et al., 2011; Neigh et al. 2013). Particularly, ecosystems at northern latitudes have become the focus of recent research (e.g. Callaghan et al., 2010; Tank et al. 2012; Neigh et al. 2013). This is not only because these ecosystems are large potential sinks of carbon in the atmosphere but also because they are very sensitive to

climate change (Price and Apps, 1996; Betts, 2000; Callaghan et al., 2010). Therefore, understanding the role and importance of boreal ecosystems in global carbon cycle is crucial to our assessment of future global environmental change. Unfortunately, however, in most cases riverine carbon exported from terrestrial systems, which plays a key part in linking terrestrial, aquatic and atmospheric carbon cycles, is rarely mentioned when discussing terrestrial or global carbon budgets. In reality, inland waters (including streams, rivers, lakes and wetlands) occupy less than 1% of the Earth's surface, but their collective contribution to the global carbon fluxes is disproportionately important, compared with terrestrial and oceanic ecosystems (Battin *et al.*, 2009). Especially in recent years, the relative contribution of inland waters to the global carbon budget has been further highlighted (Cole et al., 2007; Battin et al., 2009; Benstead and Leigh, 2012; Raymond et al., 2013). How much carbon is exported from watersheds, in what form, and when the exports occur, as well as the future response of riverine carbon export to global warming have thus become hot issues of major biogeochemical interest. Although there are aspects of the role and importance of river system in regional carbon budgets that are relatively well understood, there are still many uncertainties, particularly in terms of the magnitude of some of the key processes involved. For example, the estimates of global CO_2 evasion from inland waters range from 0.26 to 3 Pg C (Cole et al., 2007; Aufdenkampe et al., 2011; Raymond et al., 2013; Lauerwald et al., 2015). Although the estimates of organic carbon transported from land to sea ranging widely from 0.03 to 1 Pg C yr^{-1} (Williams, 1971; Reiners, 1973; Richey et al., 1980; Meybeck, 1982; Ludwig et al., 1996; Schlunz and Schneider, 2000; Aitkenhead and McDowell, 2000) have been converged to a value of around 0.4 Pg C yr^{-1}, the exact quantity still remains elusive because previous studies were based on the limited data, given

similar assumptions, and/or commonly biased to some big rivers, especially tropical and temperate (Likens et al., 1981; Meybeck, 1993; Ludwig et al., 1996; Cauwet, 2002; Dai et al., 2012). As for global particulate carbon export, there may be more uncertainties in the estimates because almost all the previous estimations were merely based on an assumed percentage of particulate organic or inorganic carbon (POC or PIC) in suspended matter, lacking strong supporting data (Garrel et al., 1973; Likens et al., 1981; Meybeck, 1982; Ludwig et al., 1996; Cauwet, 2002), although Meybeck (1982) and Galy et al. (2015) estimated global riverine POC export based on the POC and sediment data of 100 and 70 rivers, respectively. It is thus necessary to develop a better understanding of the role and importance of river systems or inland waters in linking atmospheric, terrestrial and aquatic carbon cycling, both regionally and globally, in the context of global warming.

0.2 Environmental controls on riverine carbon export from watersheds at landscape scale

River systems connect the atmosphere, hydrosphere, geosphere and biosphere, so export of carbon from watersheds to river systems is widely regarded as an essential component of regional and global carbon cycling. Especially, headwater streams, the sources of river networks, have tight carbon linkages to their surrounding terrestrial environments from hill slopes to stream channels, and are shaped substantially by interactions among hydrological, geomorphical and biological processes that are associated closely with the biogeochemical cycling of carbon. Hence, they are controlled greatly by landscape variables and regulate the cycling of nutrients (e.g. N, P, Fe, S) that potentially subsidize the aquatic communities in the downstream reaches or within the entire watershed (Gomi et al., 2002; Wipfli et al., 2007).

Therefore, the study on landscape controls on carbon export from watersheds scaling from a headwater catchment to the globe is necessary to integrate inland waters into the terrestrial and global carbon budgets, undoubtedly beneficial to better understanding of biogeochemical cycles of carbon and nutrients in the background of global change.

However, landscapes differentiate at different spatial and temporal scales due to the heterogeneous combinations of climate, soil, vegetation, lithology, landform and land use/cover, thus resulting in different riverine carbon export patterns that are characterized by different composition of carbon species that are exported from the watersheds and then transformed along the river. In addition, human activity has become an important driving force for global change and this further complicates the study of the controlling effects of landscape on riverine carbon export from the landscapes due to anthropogenic impacts on the earth surface and regional and global carbon balances (e.g. deforestation, farming, damming and urbanization) (e.g. Meyer & Tate, 1983; Carignan et al., 2000; Westerhoff and Anning, 2000; Daniel et al. 2002; Royer and David 2005; Laudon et al., 2009; Wilson and Xenopoulos, 2009; Hudon and Carignan, 2008; Barnes & Raymond, 2009; Alvarez-Cobelas et al., 2012; Bauer et al., 2013). Therefore, more attention should be focused on natural and anthropogenic effects on carbon export from catchments to rivers, mechanistically and quantitatively, at different temporal and spatial scales, and on integrating of riverine carbon into terrestrial and global carbon cycles.

The carbon exported from catchments to river systems can generally be classified into dissolved organic carbon (DOC) (<0.45μm), resulting from leaching and decomposition of organic carbon in plants and soils, dissolved inorganic carbon

(DIC), such as HCO_3^-, CO_3^{-2} and H_2CO_3 (or dissolved CO_2), POC (>0.45μm), including litter, wood debris, insects and soil organics, and PIC, debris of carbonate minerals. Ultimately, the C that is loaded from land into river networks will in part evade as CO_2 and CH_4 to the atmosphere, in part will flow downstream to the receiving water bodies or oceans, and the rest will enter aquatic food webs or be stored in sediments in streams, rivers, lakes and/or coastal oceans. On a catchment basis, the carbon from landscapes is finally transported out of the catchment in dissolved (DOC, DIC and dissolved CH_4), gaseous (CO_2 and CH_4) and particulate (POC and PIC) forms. According to Meybeck (1982 & 1993), about 0.9 petagrams (Pg) C is annually delivered to the oceans via rivers, of which 0.4 Pg of organic carbon (DOC and POC) is from soil organic carbon, 0.3 Pg of inorganic carbon (DIC and PIC) is from erosion of carbonate rocks in continental crust, and the other 0.2 Pg is DIC from soil inorganic carbon. In reality, the main carbon forms in the river are DOC, DIC and POC since PIC and dissolved CH_4 account for a very small fraction of riverine carbon exported (Aucour et al., 1999; Billett & Moore, 2008; Li et al., 2015) and few studies were/are focused on them for their relatively less importance in ecology and environmental science. Figure 1 shows the biogeochemistry of carbon in rivers, indicating the sources and fates of riverine carbon from terrestrial organic carbon may be respired, ingested, stored, exported and flocculated, while DIC may be lost through CO_2 evasion. Recently, the global CO_2 evasion from inland waters is estimated from 0.26 to 3 Pg C (Cole et al., 2007; Aufdenkampe et al., 2011; Raymond et al., 2013; Lauerwald et al., 2015), while the global CH_4 evasion is estimated as 0.1 Pg (Bastviken et al. 2011). Moreover, due to the landscape heterogeneity, carbon export from different landscapes to river systems varies widely around the world----for example, DOC export ranges from 0.5 (Mulholland and Watts, 1982) to

416 g m^{-2} yr^{-1} (Charzanowski et al., 1983) while riverine DIC export varies from 0.03 (Stets & Striegl, 2012) to 115.12 g m^{-2} yr^{-1} (Tript et al., 2013; Sarma et al., 2012).

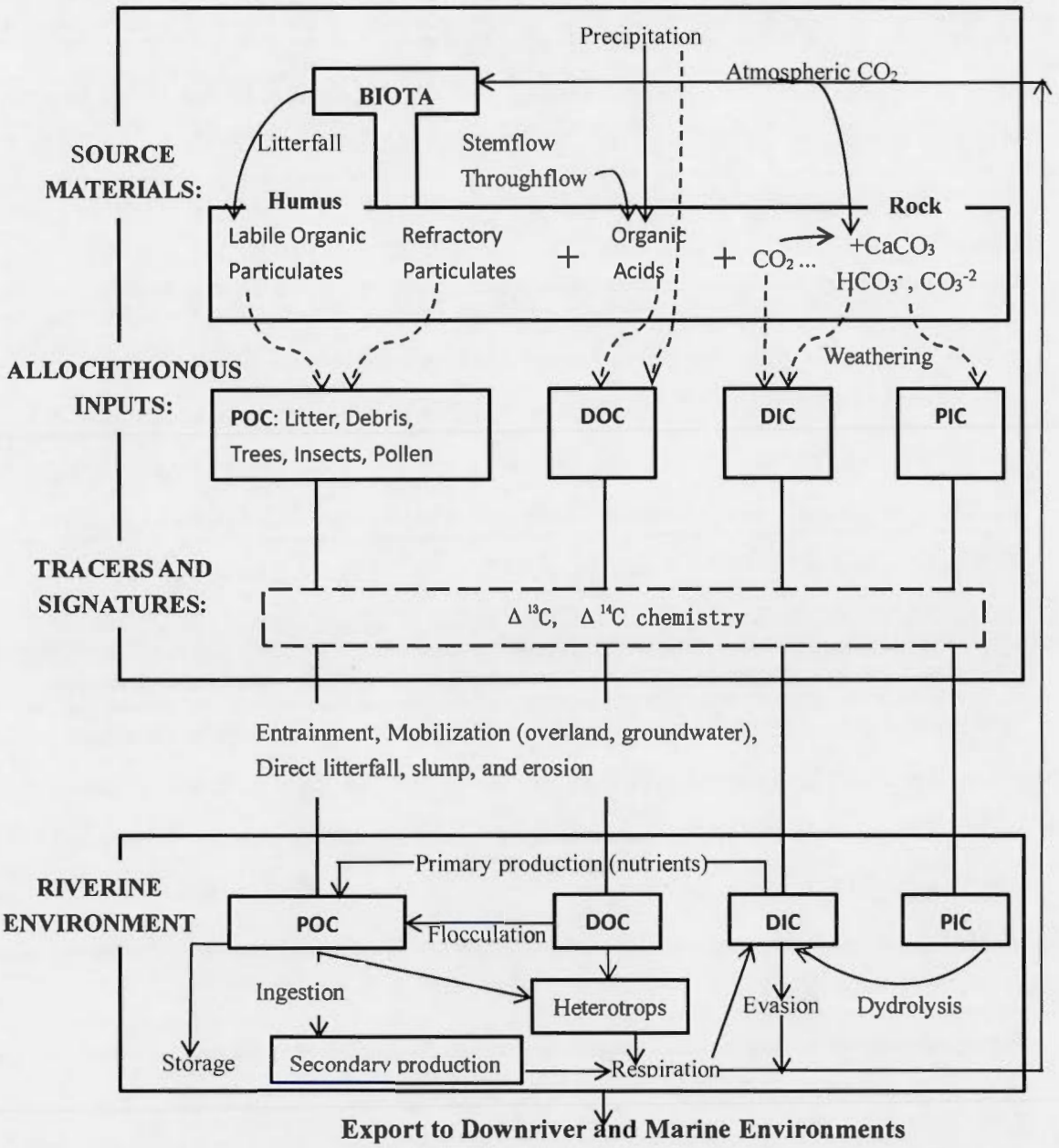

Figure 1 The biogeochemistry of riverine carbon (modified from Likens (1981))

Over the past 30 years, great effort has been, to varying degrees, made to better understand and quantify riverine TOC (total organic carbon), DOC, POC, DIC (e.g. Schlesinger and Melack, 1981; Mulholland & Watts, 1982; Hope et al., 1994; Ludwig et al., 1996; Stets and Striegl 2012; Tank et al., 2012; Lapierre et al., 2013; Dornblaser & Striegl, 2015; Galy et al., 2015), and evasion of CO_2 and CH_4 (e.g. Kling et al., 1991; Battin et al., 2009; Aufdenkampe et al., 2011; Butman & Raymond, 2011; Lapierre et al., 2013; Raymond et al., 2013; Campeau et al., 2014; Lauerwald et al., 2015). In particular, the export of terrestrial organic carbon (DOC or TOC) to river systems has been the focus of attention, because it may influence aquatic metabolism and nutrient cycling, is linked to carbon emissions to the atmosphere, and closely relates to water quality (e.g. influence on the mobility and availability of metals and contaminants) (e.g. Schlesinger and Melack, 1981; Mulholland & Watts, 1982; Hope et al., 1994; Ludwig et al., 1996; Mulholland, 1997; Lal, 2003; Alvarez-Cobelas et al., 2012; Lapierre et al., 2013; Larouche et al., 2015). The influence of landscape variables on riverine DOC export also has been addressed widely from different perspectives, such as climate (e.g. Prokushkin et al., 2005; Raymond & Oh, 2007; Tetzlaff et al., 2007; Köhler et al., 2008; Lepisto et al, 2014), hydrology (e.g. Hornberger et al., 1994; Hein et al., 2003; Johnson et al., 2006; Dawson et al., 2008; Kawasaki et al., 2008), geology (e.g. Telmer and Veizer, 1999; Liu et al., 2000; Inamdar & Mitchell, 2006; Cai et al., 2008; Lloret et al., 2011), topography (e.g. D'Arcy and Carignan, 1997; Johnson et al., 2000; Pacific et al., 2010), soil (e.g. Aitkenhead and McDowell, 2000; Palmer et al., 2001; Haei et al., 2010), wildfire (e.g. Marchand et al.,2009; Larouche et al., 2015), and land use/cover (e.g. Carignan et al., 2000; France et al., 2000; Wilson and Xenopoulos, 2009; Laudon et al., 2009; Regnier et al., 2015). The export of DIC from watersheds to

aquatic ecosystems, on the other hand, appears to be linked to regional geology, especially underlying carbonate and siliceous rocks, as well as land-use/cover plays important roles in controlling riverine DIC export (e.g. Liu et al., 2000; Raymond & Cole, 2003; Zhang et al., 2009; Li et al., 2010; Regnier et al., 2015). Dornblaser & Striegl (2015) also found that DIC export greatly depends on subsurface flow in boreal regions while in tropical region DIC is mainly flushed from surface soil layers (Markewitz et al., 2001). The effects of other landscape variables on riverine DIC export are not clear or less explored. Overall, at a regional scale, it would appear that catchment topography and hydrology (D'Arcy et al., 1997; Inamdar & Mitchell, 2006; Mengistu et al. 2014), climate (Schindler et al., 1997) and catchment vegetation (France et al., 2000; Lepisto et al, 2014) are the most important drivers of DOC export, whereas geology is more dominant than land-use in controlling riverine DIC export (e.g. Liu et al., 2000; Zhang et al., 2011; Tank et al., 2012). Given that the controls of climate and hydrology on carbon export from catchments have well understood relatively, topography and land-use/cover inevitably become the main determinants of the regional differentiation of carbon exports from catchments. In particular, few studies have simultaneously addressed the controls of topography and land-use/cover on DOC, DIC and TC exports from watersheds to aquatic ecosystems and explored the functional and mechanical differences of the variables in controlling the magnitude and composition of the carbon exported from the landscape.

Furthermore, previous studies on topographical controls on DOC export have shown that the DOC export has strong negative relationships with catchment slope (e.g. Eckhardt et al., 1990; D'Arcy et al., 1997; Hazlett et al., 2008) and catchment area (Ågren et al., 2007). However, the opposite findings that Wolock et al. (1997) reported a strong negative relationship between DOC concentration and catchment

area while Inamdar & Mitchell (2006) separately reported a positive one between them have further blurred the catchment size effect on DOC export, but indicated that the relationship is site-specific. As for the studies on the relationship between DIC export and topography, it was mainly limited to the influence of topographical position on DIC concentration (e.g. Gburek and Folmar, 1999; Kling et al., 2000; McGlynn and McDonnell, 2003), accordingly affecting riverine DIC export. With respect to land-use/cover effect on carbon export, it has been found that the reduction of natural vegetation due to logging, farming, pasturing or urbanizing could pronouncedly increase riverine DIC export (e.g. Daniel et al. 2002; Raymond & Cole, 2003; Baker et al., 2008; Barnes & Raymond, 2009; Regnier et al., 2015) but had varying influence on DOC export to aquatic ecosystems. For example, most studies found that forest-harvesting in catchments could significantly increase DOC export to receiving waters (e.g. Carignan et al., 2000; France et al. 2000; Lamontagne et al., 2000; Nieminen, 2004; O'Driscoll et al., 2006; Laudon et al., 2009; Winkler et al., 2009). However, some noted that clear-cutting caused little change in DOC export (Hobbie & Likens, 1973; McDowell & Likens, 1988; Moore & Jackson, 1989; Piirainen et al. 2002), and several even found that clear-cutting could significantly reduce DOC export from forested watersheds (Meyer & Tate, 1983; McLaughlin and Phillips, 2006). As for farming effects on DOC export, some reported that agricultural streams (affected by crops and livestock grazing) were often of lower DOC export than streams in forest-, wetland- and heathland-dominated catchments (e.g. Cronan et al. 1999; Royer and David 2005; Alvarez-Cobelas et al., 2010), while some others addressed that agricultural land use had no pronounced influence on DOC export from the watersheds (Vidon et al., 2008; Wilson and Xenopoulos, 2009). Reversely, a significant positive relationship between agricultural use and catchment DOC export

was collectively supported by the 24-year survey of cropping effect on organic discharge from the Rhone river watershed in USA (Correll et al., 2001), the statistical analysis of varied boreal catchments in Finland (Rantakari & Kortelainen, 2008) and the field measurements in Zhujiang River, China (Sun et al., 2010; Zhang et al., 2011). Nevertheless, the relative importance of topography and land-use/cover on DOC, DIC or TC export and the effects of landscape variables on composition of total riverine carbon exported from the landscape have been rarely reported. Especially in the background of global environmental change driven largely by anthropogenic disturbances, it is thus necessary to further explore the relative effects of topography and land-use/cover change on the magnitude and composition of the carbon exported from watersheds to aquatic ecosystems, thus better understanding the role and importance of the river carbon exported from the watershed in terrestrial and global carbon cycles.

0.3 Total carbon export from watersheds to river systems

As mentioned above, most previous studies have focused separately on exploring the loading of individual C components (TOC, DOC, POC and DIC) and degassing of the total carbon exported from the watersheds (Mulholland and Watts, 1982; Hope et al., 1994; Alvarez-Cobelas et al., 2012; Hossler and Bauer, 2013). Although a considerable insight into the dynamics of specific carbon forms has been gained with this approach, it nevertheless has yielded a rather fragmented view of the magnitude and regulation of TC export from watersheds, and of the relative importance of different individual carbon species and potential interactions between them. In addition, the few studies that have quantified TC export and compared dissolved carbon export and degassed CO_2 and CH_4, most of these, were limited to one or

several small catchment(s) (Hope et al., 2001; Billett et al., 2008; Dinsmore et al., 2013; Wallin et al,. 2013). It is currently still difficult to produce an integrated view of TC exported from landscapes to river systems and to characterize the spatial-temporal differences of TC and its composition. To develop a better understanding of the export of terrestrial carbon to river systems requires simultaneous observation of the main components of riverine carbon from the landscape across a range of landscape types, watershed sizes and climate, both theoretically and practically. Only in this way, can the magnitude and composition of total carbon exported to river systems be quantified at different space/time scales, and hence a better understanding of carbon export from watersheds be realized from the integrated perspective.

0.4 Objectives of the thesis

The general objective of this thesis is to explore the magnitude and controls of carbon export from watersheds to rivers, scaling from regional to global levels. It has been divided into 3 sub-objectives: 1) to better understand natural and anthropogenic effects on carbon export from temperate watersheds and the response of riverine carbon export to human activities in the context of global warming; 2) to identify the magnitude of TC export from boreal landscape, characterize the spatial-temporal alteration of carbon composition of the TC exported (DOC, DIC, POC, PIC, CO_2 and CH_4), and explore the regional TC export pattern in Quebec; 3) to upscale the regional studies on riverine carbon export to the global scale so as to clarify the major natural and anthropogenic drivers on global riverine carbon to the oceans through a meta-analysis. The regional studies in the thesis are based on 127 river catchments (83 and 44 in temperate and boreal regions, respectively) in Quebec for which the

Aquatic group at Université du Québec à Montréal had made direct measurements over the course of past 10 years, and which were used to explore the regional TC export patterns. In addition, a global dataset of published data comprising 566 rivers was assembled to revisit the global TC export patterns in the context of global warming and re-estimate the global riverine carbon budget from the land to the ocean and to explore natural and anthropogenic drivers on global riverine carbon export at the global scale.

The three sub-objectives of this thesis have been presented as the three chapters, which are separately written in the form of scientific article:

Chapter 1 The relative influence of topography and land cover on inorganic and organic carbon export from catchments in southern Quebec, Canada.

Chapter 2 Magnitude and composition of carbon exported from boreal catchments to river systems in northern Quebec, Canada.

Chapter 3 A global analysis of riverine carbon export to the oceans.

Through these regional and global studies, the export of carbon from watersheds to aquatic ecosystems will be better understood and some beneficial bases for the further study on global carbon cycle and climate change could be provided.

0.5 General scopes and approaches

This thesis aims at exploring the carbon export from watersheds to aquatic ecosystems and integrating river systems into regional and global carbon cycles or budgets. The scope of the studies is focused on carbon export from land to river systems, its main climatic, hydrologic, geomorphic and biological drivers, and the potential influence of human activities at the scales varying from a catchment to the

globe. Therefore, a series of mixed approaches (e.g. collecting data, characterizing catchments, making models) are applied to explore the regional spatial-temporal patterns of carbon export from watersheds to aquatic ecosystem in the natural environment so as to upscale this study from a catchment to the globe.

0.5.1 Regional riverine carbon export from northern catchments

In this thesis, I used the data of 127 rivers and streams in Quebec, of which 83 and 44 are respectively in temperate and boreal regions (see Figure 2), that had been intensively sampled, respectively, for 1 to 3 years. For each sampled system, a series of physical (temperature, discharge, pCO_2 etc.) and chemical (pH value, concentrations of DOC, DIC and nutrients, and fluxes of CO_2 and CH_4) were measured or calculated, so as to link them to riverine carbon exported from the landscapes. Topographic (e.g. slope, elevation, shape and area of a catchment) and land use/cover (e.g. forest%, vegetation%, pasture%, wetland%, lake%) variables were extracted from the digitized maps using ArcGIS 10 and used to characterize each catchment. Then riverine carbon exported from each catchment was calculated as the product of discharge and DOC and DIC concentrations. The evasion of CO_2 and CH_4 from surface waters was adjusted to the fluxes from the entire catchment area. Finally, TC export from watersheds to rivers was estimated from the sum of these components, and I explored the relative contribution of the various C components (DOC, DIC, CO_2) to TC export, and its drivers using a series single or multiple linear regression models.

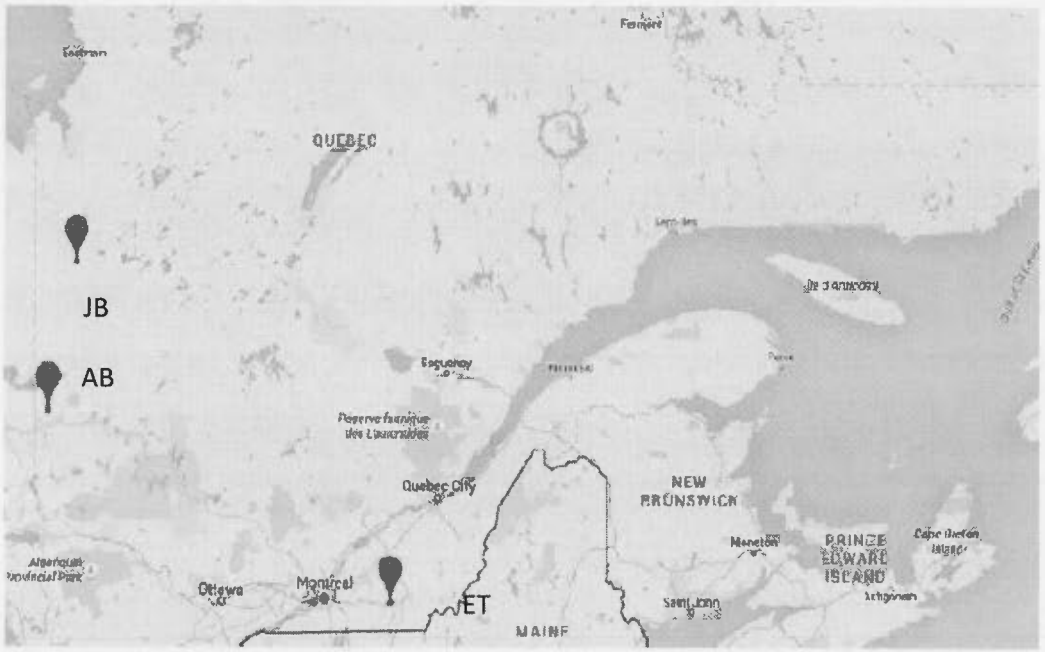

Figure 2 The research areas for the regional studies on riverine carbon export (ET: Eastern Townships; JB: James Bay; AB: Abitibi. JB and AB, two sub-regions of this study area, are closely neighbored in northern lowland of Quebec)

0.5.2 A meta-analysis up-scaling to global riverine carbon export to the oceans

I carried out the meta-analysis of published data on river C concentration and export that were collected from publications and technical reports published mostly after year 2000, covering 566 rivers worldwide, draining 74% of global exoreic area. The catchments for which I collected data are shown in the map (Figure. 3 & Appendix A). The data on catchment area and multi-year average river discharge were taken mostly from Meybeck and Ragu (1996) (www.unep.org), while others based on the specific references. All the river mouth coordinates have been identified with Google Maps. River length and elevation in watersheds were mostly collected from

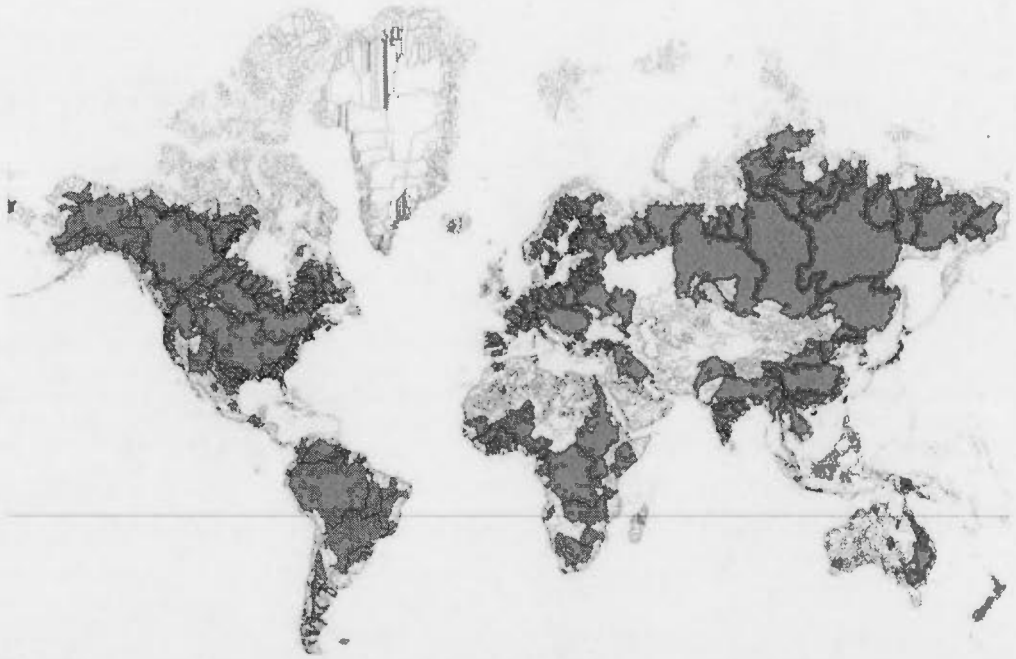

Figure 3 The total sampled catchment area (in brown) is 56% of the global terrestrial area, covering 74% of the global exorheic area (excluding Antarctica)

http://www.waterfootprint.org. Soil organic carbon, percent land cover/use and percent carbonate in the catchments were extracted respectively from the global land use/cover and geological map using ArcGIS 10. We only included studies that had followed riverine DOC, DIC, POC or PIC concentrations and exports for at least one full annual cycle. Some big rivers studied by different groups, in which case we used the average of the river carbon concentrations or exports reported in the various studies. Multiple linear regression model is used to explore the relationships of riverine DOC, DIC, POC and PIC exports to environmental variables and human activities. The carbon export models we made are used to estimate the riverine carbon export of the other watersheds to the oceans and the missing C data of the 566 rivers, and predict the future trend of global riverine carbon export from land to sea in the context of global warming and under the pressure of cropland expansion.

0.5.3 Statistical analysis

Simple and multiple linear regressions and covariance analyses (ANCOVA) were used to identify the relationships between carbon export/concentration and environmental variables and test significant differences in the regional and global patterns of riverine carbon export. Data were log10 transformed sometimes so as to satisfy the conditions of homoscedasticity and normality. In all the statistical analyses, the threshold for significance is $P<0.05$. Statistical analyses were carried out on JMP 9.3 (SAS institute).

N.B. References cited in the introduction are presented at the end of the thesis.

CHAPTER I

THE RELATIVE INFLUENCE OF TOPOGRAPHY AND LAND COVER ON INORGANIC AND ORGANIC CARBON EXPORT FROM CATCHMENTS IN SOUTHERN QUEBEC, CANADA

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N.B. References cited in this chapter are presented at the end of the thesis.

1.1 Abstract

Export of carbon (C) from watersheds represents a key component of local and regional C budgets. We explored the magnitude, variability and drivers of inorganic, organic and total C export from 83 temperate catchments in southern Québec, Canada. The average dissolved inorganic (DIC), dissolved organic (DOC) and total C (TC) exports from these catchments were 4.6, 5.1 and 10.2 g m^{-2} yr^{-1}, respectively. Multiple regression models, using a combination of topographical variables (catchment area, shape and slope), along with land-cover variables (%vegetation, %wetland, %lake and building density), explained 34%, 62% and 53% of the variability in the DIC, DOC, and TC exports, respectively. An examination of variance partitioning in the models revealed that topography is slightly more important than land cover in explaining the variance in DIC export (19% vs 15%),

whereas land cover is much more important than topography in determining DOC export (44% vs 18%). Interestingly, %vegetation had a negative effect on DIC export but a positive effect on DOC export, suggesting that a change in land cover that reduces vegetation (e.g. deforestation) would lead to modest decreases in TC export, but large increases in the DIC/DOC export ratio. We conclude that topography and land cover together determine DIC, DOC and TC exports. While topography is static, land cover can be altered, which will determine the quantity, form and by extension the fate of C exported from these catchments. Finally, annual differences in export values that are related to temperature and precipitation suggest that climate change also have an impact on C export.

Key words: riverine carbon export; DOC; DIC; topography; land cover; carbon cycle

1.2 Introduction

The export of materials from land to fluvial networks and eventually to the ocean has been a major focus of research for decades (*Likens and Bormann*, 1974; *Dillon and Molot, 2005*; *Hossler and Bauer*, 2013). Not only are these land-derived materials transported and transformed during transport, they also influence the functioning of the receiving aquatic ecosystems (*Cole and Caraco,* 2001*; Aufdenkampe et al.,* 2011). More recently, lateral inputs of C from watersheds have been recognized as important not just to inland and coastal waters, but also to our understanding of the terrestrial C budget as well (*Cole et al., 2007; Battin et al.*, 2009; *Buffam et al., 2011*; *Stets and Striegl*, 2012; *Dornblaser and Striegl*, 2015). Most of the dissolved and particulate organic C exported from watersheds originates from terrestrial primary production (*Kardjilov et al.*, 2006; *Wilkinson et al.*, 2013; *Galy et al.*, 2015). Similarly, most of the DIC is ultimately of biological origin because bicarbonate and carbonate ions are

derived from the interaction between respiratory soil CO_2 and soil minerals through the process of chemical weathering (*Liu et al.*, 2000; *Zhang et al.*, 2009; *Tank et al.*, 2012; *Wang et al.*, 2012). Regardless of its origin, C export ultimately represents a loss of terrestrial primary production that needs to be accounted for in regional C budgets. How much C is lost from watersheds, in what form, and when these exports occur, are issues of major biogeochemical interest.

The form in which C is exported is of critical importance in determining its fate. It largely dictates the extent to which the C will either be retained in the local aquatic system, released to the atmosphere, stored in sediments, or transported downstream, because different forms are not regulated by the same biological, chemical, and physical processes. For example, a significant portion of the DOC entering aquatic systems is transformed by micro-organisms, such that it is either incorporated into biomass or respired as an energy source (*Tranvik*, 1992; *Neff and Asner*, 2001). DOC is also affected by photo-chemical processes that may mineralize into CO_2 (*Lapierre et al.*, 2013), render it more susceptible to microbial processes, or even flocculate into POC (*von Wachenfeldt et al.*, 2008, 2009). In contrast, the ionic fraction of DIC (i.e. CO_3^{2-} and HCO_3^-) is likely to behave in a more conservative manner (*Zhai et al.*, 2007; *MacPherson et al.*, 2008), whereas the dissolved CO_2 fraction will be largely lost to the atmosphere, with some being assimilated during photosynthesis (*Striegl et al.*, 2012; *Wallin et al.*, 2013). Because DOC and DIC are processed differently in aquatic systems, the two C species will impact C budgets in different ways and thus should be examined individually. It follows from this that the export of these two general forms of C (DIC and DOC) will likely not be driven by the same factors.

A review of the literature shows that DOC export is at least partly dependent on aspects of catchment topography, such as slope (*Eckhardt and Moore*, 1990; *D'Arcy and Carignan*, 1997; *Hazlett et al.*, 2008), area (*Mulholland*, 1997; *France et al.*, 2000; *Ågren et al.*, 2007), or elevation (*Johnson et al.* 2000; *Hazlett and Foster*, 2002). However, land cover changes, such as deforestation, also have an influence on DOC export (*Meyer and Tate*, 1983; *Carignan et al.*, 2000; *McLaughlin and Phillips*, 2006; *France et al.*, 1996; *Wilson and Xenopoulos*, 2008). Although wetlands are widely regarded as sources of DOC, wetland loss due to human activities can have varying effects on DOC export, depending on land use and management practices (*Royer and David*, 2005; *Armstrong et al.*, 2010; *Stanley et al.*, 2012). External forcing, such as hydrology (*Eckhardt and Moore*, 1990; *D'Arcy and Carignan*, 1997) and climate (*Freeman et al.*, 2001; *Raymond and Ho*, 2007; *Räike et al.*, 2012; *Lepisto et al.*, 2014) also strongly modulate DOC export.

Dissolved inorganic carbon export, on the other hand, is influenced by catchment geology, in particular by the presence of carbonate deposits in the catchment (*Liu et al.*, 2000; *Zhang et al.*, 2009; *Tank et al.*, 2012). Some studies have noted that topographical position and basin elevation have a marked effect on concentration and export of DIC from watersheds (*Soranno et al.*, 1999; *Kling et al.*, 2000; *Finlay et al.*, 2010). Others have shown that changes in land cover affect DIC export, for example, through logging, farming, pasturing or urbanization (*Daniel et al.*, 2002; *Raymond and Cole*, 2003; *Baker et al.*, 2008; *Barnes and Raymond*, 2009; *Regnier et al.*, 2013). Topographical position and land cover likely interact with geology, and collectively determine the degree of weathering of the underlying rocks, the principal source of carbonate and bicarbonate ions. This interaction between topography and land cover underscores the need for an integrated approach.

Most studies to date have explored DIC and DOC export separately (*Hope et al.*, 1994; Wallin *et al.*, 2010), and although there is considerable insight to be gained with this form-specific approach, it nevertheless yields a rather fragmented view of the magnitude and regulation of total C export from watersheds. Since the relative influence of topography and land cover may be different for DIC and DOC export, changes in land cover may lead to shifts not only in total C export, but also in the DIC/DOC export ratio. Here we explore topographic and land cover predictors of DIC, DOC, and TC exports in a set of 83 diverse catchments, located in the temperate landscape of southern Québec. The main objectives of this research were three-fold: (1) to identify the relative importance of topography and land cover on DIC, DOC, and TC export from temperate watersheds, (2) to explore the effect of potential land cover changes on the DIC/DOC export ratio, and (3) to compare DIC and DOC exports across 3 consecutive years of varying hydrologic regimes.

1.3 Materials and methods

1.3.1 Study area

Estimating carbon export from a large number of catchments over several years requires a considerable sampling effort and necessarily involves a compromise between capturing the temporal (within streams) and spatial (among streams) components of variability. As our focus centered on identifying the landscape drivers most closely associated with export rates, we opted to maximize landscape variability while ensuring a sufficient temporal coverage to obtain robust estimates of annual export of the various carbon forms. We therefore selected 83 catchments in southern Québec, Canada, about 100 km east of Montreal (45°12'17"N - 45°49'22"N, 71°49'34"W - 72°39'50"W), ranging in area from 0.13 to 520 km^2 (Table 1). The

streams and rivers draining these catchments were sampled in 2004 and 2005, and a subset (32) were also sampled in 2003. The rivers sampled range from first order streams to fourth order rivers. Vegetation in the watersheds is characterized by mixed temperate forest, dominated by native sugar maple trees, mixed with basswood, red oak, eastern white pine, eastern hemlock, and yellow birch. Land use varied greatly among catchments, some being largely forested, others dominated by agriculture or pasturelands (Table 1). Geologically, the study area is located in the transition region between the Humber and Dunnage Zones of the Appalachian Uplands striking northeastwards, has rolling topography, controlled by a series of well-developed faults and folds, is underlain by carbonate-rich and non-calcareous siliceous sedimentary rocks, imbedded with mudstone and sandstone, and is dotted with outcrops of metamorphic and igneous rocks (*Tremblay and St-Julien*, 1990; *Robinson and Fyson*, 1976; *Paradis and Lavoie*, 1996). The geology is thus quite diverse across the 83 catchments, with the dominant rock type being sedimentary in 56 catchments, volcanic in 18, and intrusive in the remaining 9. The surface deposits in the region consist mostly of glacial till and some glacio-lacustrine fine sediment (*Prairie et al.*, 2002), such that the dominant general formation is till in 19 of the catchments studied, mud in 6, although rock is the dominant formation in the majority of the catchments in this study (58). Soils are mainly humo-ferric podzolic and dystric brunisolic, with a loamy to sandy loam texture and moderate to good internal drainage, such that the dominant soil order is podzolic in 49 catchments and brunisolic in 23 catchments. Gleysolic soils dominate in 10 catchments and only 1 catchment is dominated by younger regosolic soils. Mean annual precipitation in the region is about 1000 mm, of which 500-600 mm runs off (*Natural Resources Canada*, 2009), and mean daily

temperature in July is about 18°C, while in January it is about -10°C (*Environment Canada*, 1981-2010).

1.3.2 Sampling, analyses and calculations

The 83 sites were visited 4-6 times each in 2004 and 2005, at about 5-week intervals during the ice-free period between March and November (totaling around 400 site visits per year), and a subset of 32 sites were visited an additional 6-7 times in 2003, at about 4-week intervals between March and October (totaling around 200 site visits). At each of these sites, water samples were collected and filtered in situ using 0.45 μm syringe filters and transported to the lab in 40 mL glass vials with silicone septa (I-CHEM). DIC and DOC concentrations were determined following acidification and oxidation with phosphoric acid and sodium persulfate, respectively, using a TOC1010 total carbon analyzer, equipped with an infrared CO_2 detector (OI Analytical, 2% precision of 2 replicates per vial, 3% accuracy at 5mg L^{-1} standard).

The carbon export (g m^{-2} yr^{-1}) at any given site is defined as the product of discharge and C concentration per unit catchment area, and it is therefore essential to determine the first two components accurately. We determined discharge (m^3 s^{-1}) at each site for each sampling date as the product of the measured stream cross-sectional area and water velocity (sampled at 0.6 x stream depth at several stations across the stream width using the two-dimensional FlowTracker acoustic Doppler velocimeter, SonTek). These point measurements are however, inadequate to capture the seasonal variation in discharge, and because the vast majority of these rivers are not gauged it was necessary to develop alternative approaches to reconstruct the full annual discharge pattern for each river. We developed an empirical calibration that would allow us to estimate the discharge for any given river at any given point in time, that is based on

Table 1. Stream and catchment characteristics of the 83 study sites. Statistics for discharge and water chemistry were determined by first averaging all measured values from 2004 and 2005 for each of the 83 streams, then calculating the minimum, maximum, mean and standard deviation of these values (n=83). Statistics for topography, land cover, geology and soil were obtained from digital elevation models, and maps of topography, land cover, rock type, surficial deposits, and soil order, using GIS (n=83).

Variable	Min	Mean (SD)	Max
Stream characteristics			
Discharge ($m^3 s^{-1}$)	0.0021	0.48 (1.0)	6.1
DIC concentration (mg L^{-1})	1.5	8.0 (4.1)	28
DOC concentration (mg L^{-1})	1.9	7.7 (4.0)	19
pH	6.0	7.2 (0.38)	8.1
Alkalinity (μeq L^{-1})	80	530 (280)	1800
TN concentration (mg L^{-1})	0.14	0.46 (0.19)	1.1
TP concentration (μg L^{-1})	4.1	26 (19)	110
Catchment topography			
Catchment area (km^2)	0.13	28 (79)	520
Average elevation (m)	150	310 (57)	430
Average slope ( )	1.2	5.1 (2.8)	12
BSI	1.2	1.6 (0.22)	2.4
Catchment land cover			
% vegetation	42	83 (15)	100
% forest	27	77 (18)	100
% pasture	0	21 (19)	73
% wetland	0	1.1 (1.9)	9
% lake	0	3.9 (5.9)	25
Buildings per km^2	0	9.9 (12)	56
Catchment geology and soil			
% intrusive	0	11 (27)	100
% sedimentary	0	66 (41)	100
% volcanic	0	23 (37)	100
% rock	0	69 (41)	100
% till	0	23 (38)	100
% mud	0	7.7 (24)	100
% brunisolic	0	22 (23)	91
% gleysolic	0	15 (22)	83
% organic	0	2.4 (4.1)	23
% podzolic	0	42 (30)	100
% regosolic	0	0.95 (2.5)	17

the relationship between our point discharge measurements and discharge data from a continuous gauging station located in one of our study watersheds, Trois-Lacs (TR) (hydrologic station 030101: 45°47'30"N, 71°58'5"W operated by the Centre d'expertise hydrique du Québec. The gauging station reports an error of ±5% when in the stage-discharge relationship). Our 612 instantaneous discharge measurements divided by 158 the corresponding catchment areas were expressed as runoff (mm d^{-1}), and regressed against daily runoff at the TR gauging station, along with other site-specific attributes that modulate local discharge. For this region, the best predictive model of daily runoff at any given site included elevation and catchment, in addition to the measured daily runoff at the TR station:

$$\log_{10}S_{EM} = -0.629 + 0.892*\log S_{TR} + 0.00188*E + 0.150*\log_{10}A_D \quad (1)$$

where S_{EM} is the estimated runoff at a given site (mm d^{-1}), S_{TR} is the measured value at the TR gauging station, E is the elevation of the sampling site (m), and A_D is the total catchment area upstream of the sampling site (km^2). These estimates of daily discharge generated by the empirical model correlated well with our instantaneous discharge measurements, explaining 81% of the variability (R^2=0.81, $p<0.0001$, n=612). We used this relationship to extrapolate discharge to the entire year, including winter months, for which we had no samples. While the relationships that we built between concentration and discharge were based on measurements taken during the ice-free period, we have no reason to believe that these relationships would not hold for flows under ice-cover. At the gauged site, where discharge was monitored year-round, the range of discharges recorded during the sampling season encompassed the range of discharges seen in winter. Furthermore, on the specific dates when discharge was measured at various sites and compared to the gauged discharge at Trois-Lacs on those same dates, the gauged discharges cover nearly the

full range of discharges seen throughout the year. This allowed us to derive annual export and to compare our results with the literature, which overwhelmingly reports annual export.

Daily C export was calculated as the product of daily discharge, estimated as described above, and DIC and DOC concentrations measured at each site, divided by catchment area. Applying an average DIC or DOC concentration derived from the 7 to 11 point measurements assumes that discharge and concentration are independent, which is not always the case (*Wallin et al.*, 2010; *Birgand et al.*, 2011). We tested this assumption by exploring the relationship between measured DIC and DOC concentration and measured discharge for each of our 83 sites using the data from all years combined. For DIC, significant ($p<0.05$) negative (dilution) relationships were found for 31 sites ($p<0.05$), and no sites showed a positive (concentration) relationship. For DOC, a significant dilution effect was found for only 2 sites ($p<0.05$), whereas 5 sites showed a significant concentration effect. For sites with significant correlation between concentration and discharge, we used the corresponding site-specific regression to estimate daily concentration from daily discharge. For sites with no significant relationship between discharge and DOC or DIC concentration, we applied the average concentration with the estimated daily discharge in our calculation of DOC or DIC export. Annual DIC and DOC exports (g m^{-2} yr^{-1}) were then calculated as the sum of daily export values.

Particulate organic carbon (POC) export from a catchment was not measured but rather estimated assuming a POC to DOC ratio of 0.1, typical for lotic systems in the temperate forest (*Schlesinger and Melack*, 1981; *Hope et al.*, 1994). Particulate inorganic carbon (PIC) export was not included in TC export because previous studies have shown that it accounted for a very small fraction of inorganic C (*Aucour*

et al., 1999). Thus, in this study, TC export was defined as the sum of DIC, DOC and POC exports.

1.3.3 Catchment topography and land cover

The variables used to characterize the 83 catchments are listed in Table 1. Values for topography and land cover were extracted from 1:50,000 digital topographic maps (*Natural Resources Canada*, 2006) as well as 1:50,000 and 1:250,000 land cover maps (*Natural Resources Canada*, 1999). Geological data (surficial geology and surficial materials) were obtained from 1:5,000,000 digital maps (*Natural Resources Canada*, 1995) and soil data from an amalgamation of 4 smaller regional maps ranging in scale from 1:20000 to 1:126720 (*IRDA*, 2006). Statistics were extracted from the maps using ArcMap10 (ESRI). Here, average slope (°) was derived from the digital elevation model with 10m x 10m resolution. Basin shape index (BSI), a measure of watershed roundness, is defined as the ratio of the perimeter of the catchment to that of a circle with the same area (*Miller*, 1953):

$$BSI = P/(2\sqrt{(\pi*(A_D))}) \quad (2)$$

where P and A_D are the catchment perimeter and catchment area, respectively. Geological variables are expressed as a percent of total catchment area (A_D). However, land cover and soil variables are expressed as a percent of total catchment area (A_D) minus the area of the catchment covered by waterbodies (A_W), leaving only the terrestrial catchment area (A_D-A_W). We used two different map layers of different categorical resolution to characterize the land cover properties of our catchments. In the first land cover classification, the landscape was broadly defined as vegetated, un-vegetated, and water (BNDT, Natural Resources Canada). The percent vegetated derived from this layer is a broad category that includes wooded areas and shrublands,

but excludes pastures and agricultural lands, and wetlands. The non-vegetated land includes pastures and agricultural lands, as well as bare rock (which is rare in our landscape), and therefore these two categories roughly correspond to "natural" versus "managed" landscapes. We further characterized the landscape using another landcover layer that provided a finer classification (Canada Land Inventory, Natural Resources Canada, http://sis.agr.gc.ca/cansis/publications/maps/index.html), and we derived percent forest, pasture, wetlands and mines for each of our catchment. The areas considered as forest included the zones on land cover maps classified as "productive woodland", "non-productive woodland", and "outdoor recreation", which consisted of forested parks in these catchments. The areas considered as pasture were the zones on land cover maps classified as "improved pasture and forage crops" and "unimproved pasture and rangeland". To calculate percent wetlands, regions on land cover maps that were coded as "swamp, marsh or bog" were merged with "wetlands". Land cover categorized as cropland or urban was not present in the studied catchments. Building density is expressed as the number of buildings per square kilometer of terrestrial catchment area. All the above land cover categories are expressed as % of the terrestrial area in each catchment, whereas percent lakes is the water area over the total catchment area.

1.3.4 Statistical analyses

A principal component analysis was performed on the variables describing topography, land cover, geology and soil in Table 1 to explore the multiple relationships among variables. They were then offered for inclusion in multiple linear regression models predicting DIC, DOC and TC export. The models were built using a mixed step-wise selection process, with $p<0.05$ as the condition for including a variable in the model. Both %forest and %pasture from land cover maps were

excluded from these analyses as they were strongly correlated with the broader category of %vegetation from topographic maps (%forest: positive, R^2=0.73, n=83, p<0.0001; %pasture: negative, R^2=0.72, n=83, p<0.0001), and were therefore considered redundant. The inter-annual variability in DIC and DOC export was examined for a subset of 32 catchments using a one-way analysis of variance and the Tukey-Kramer post-hoc test to find significant differences among three sequential years (p<0.05). Exports for the 32 sites were centered by expressing the export from each site in a given year as the difference relative to that site's average export over the 3 years (2003, 2004, and 2005). This procedure allowed us to examine more robustly inter-annual differences for streams with very different average export.

1.4 Results

1.4.1 Carbon export

We observed a wide range in export rates of both DIC and DOC across the 83 catchments studied. DIC export was 4.6 g m^{-2} yr^{-1} (average of 2004 and 2005 values), and ranged an order of magnitude, from 1.1 to 11 g m^{-2} yr^{-1} (Figure 1). Similarly, DOC export averaged 5.1 g m^{-2} yr^{-1} over the same period, and ranged from 1.1 to 13 g m^{-2} yr^{-1} (Figure 1). As a result, TC export averaged 10 g m^{-2} yr^{-1}, and ranged from 2.5 to 18 g m^{-2} yr^{-1}. Combining the uncertainty of both discharge and concentration estimates, error propagation calculations suggest that the export values have an associated error of about 25%.

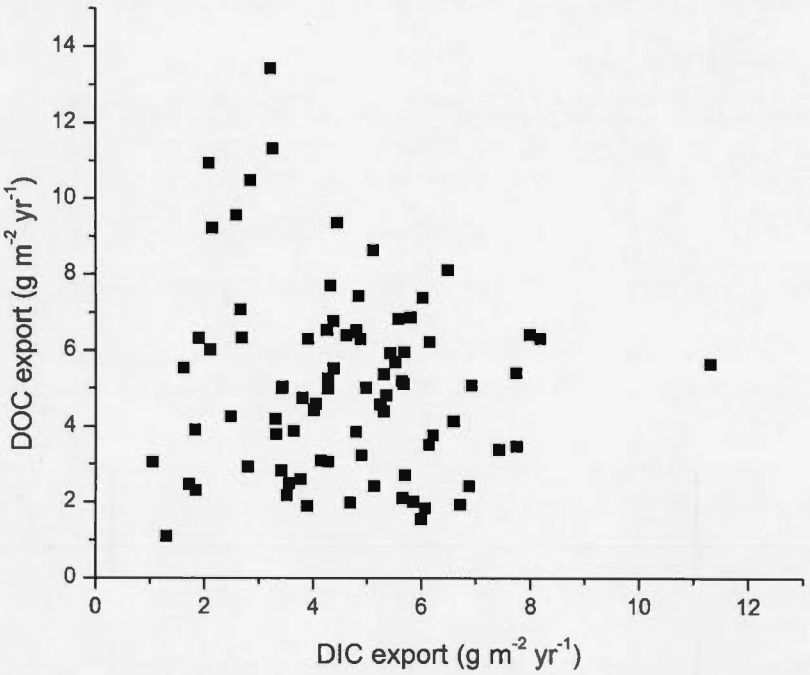

Figure 1. DOC export versus DIC export for the 83 catchments. Exports are expressed as the average of 2004 and 2005 measurements in g of C per square meter of total catchment area per year.

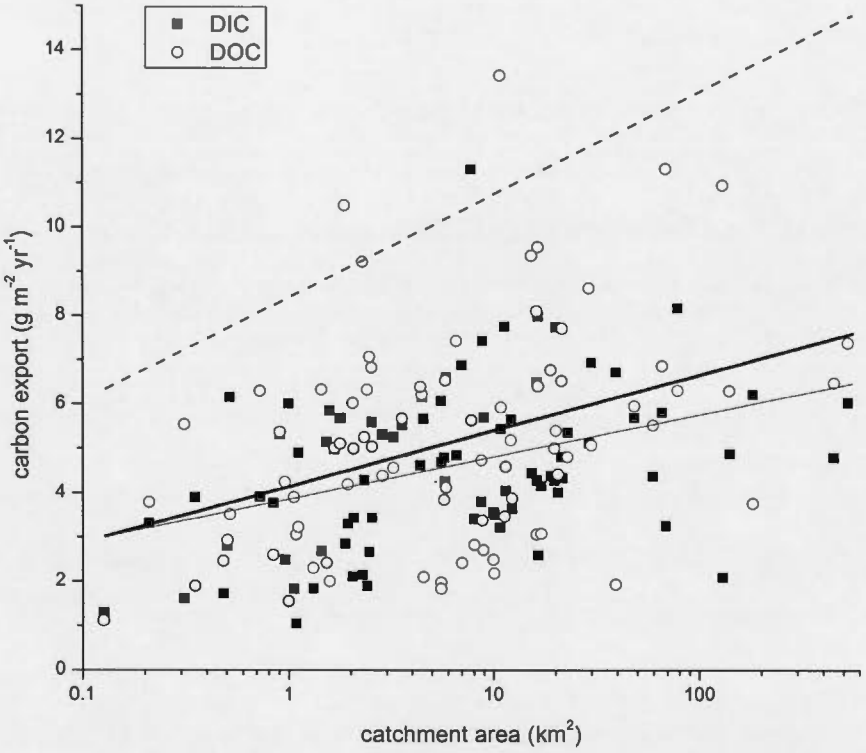

Figure 2. Carbon exported as DIC (solid squares) and DOC (open circles) in g m^{-2} yr^{-1} for the 83 catchments, average of 2004 and 2005 measurements, as a function of total catchment area. Significant correlations with catchment area are shown for DIC export (thin line), DOC export (thick line) and TC (dashed line, points not shown).

Despite the similar range and magnitude of DIC and DOC exports, there was no significant correlation between the export of these two C species. The relative contribution of the two dissolved constituents to TC export thus varied considerably among the catchments, with export from some sites being overwhelmingly dominated by inorganic C, and others by its organic counterpart. The ratio of DIC to DOC export ranged 20-fold, from 0.19 and 3.9, averaging 1.1, with 56 of the 83 catchments falling in the range between 0.5 and 2.0. In addition, the range and magnitude of DIC and

DOC concentrations (in mg L^{-1}) across the 83 sites were similar (average of 2004 and 2005 values, Table 1), yet there was no relationship between concentrations of these inorganic and organic components for the region.

Overall, there was a significant positive spatial scale effect on C export (Figure 2), such that DIC, DOC and TC exports increased with catchment size ($\log_{10}(DICexport) = 0.54 + 0.11*\log_{10}(A_D)$, $R^2=0.19$, $p<0.0001$, $n=83$; $\log_{10}(DOCexport) = 0.56 + 0.12*\log_{10}(A_D)$, $R^2=0.16$, $p=0.0002$, $n=83$; $\log_{10}(TCexport) = 0.90 + 0.11*\log_{10}(A_D)$, $R^2=0.33$, $p<0.0001$, $n=83$).

1.4.2 Factors influencing carbon export

A principal component analysis of DIC, DOC and TC exports (average of 2004 and 2005 values) as well as topographic and land cover variables demonstrates the large degree of uncoupling between DIC and DOC export, as these two variables are orthogonal to each other on the summary plot of the first 2 components (Figure 3). The first two components explained more than 50% of the variance in the data, with component 1 aligning strongly with topographical variables, such as catchment area, slope and elevation (34%), and component 2 aligning more with land cover variables, such as %vegetation and %wetlands (18%).

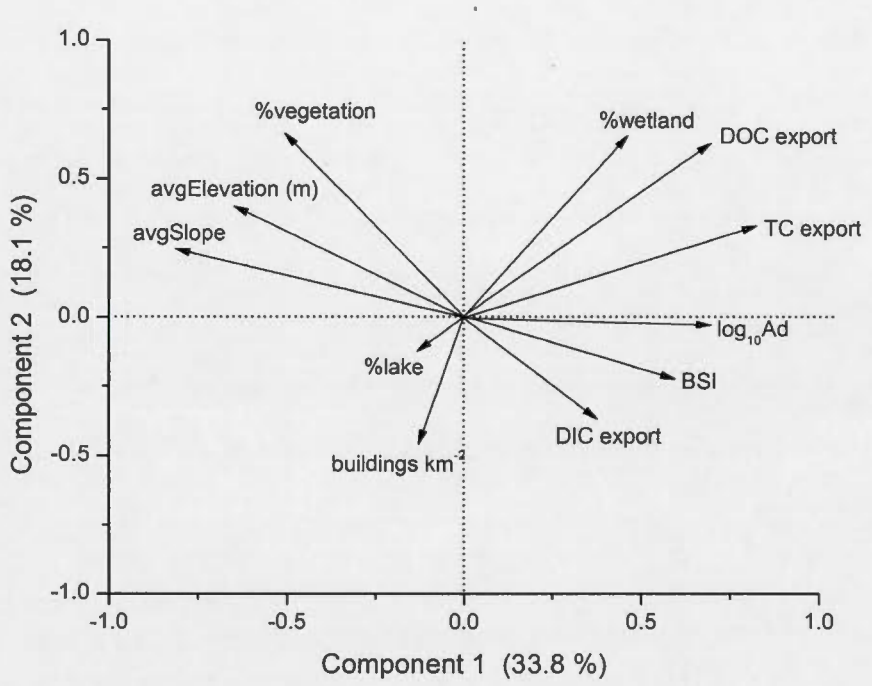

Figure 3. Principal component analysis of DIC, DOC and TC exports (average of 2004 and 2005 values) and key topographic and land-cover variables for the 83 catchments.

The position of DIC and DOC exports at 45° to the axes reveals that the export of either C component is related to a combination of the topographical variables of component 1 and the land cover variables of component 2. Not surprisingly, TC export was intermediate between DIC and DOC exports. The multiple linear regression models presented in Table 2 thus incorporate a combination of topography and land cover variables, and explain 34%, 62% and 53% of the variance in DIC, DOC and TC exports, respectively. Both DIC and DOC exports were positively

related to total catchment area (as shown in Figure 2). BSI and %vegetation both had a significant negative effect on DIC export, but a significant positive effect on DOC export. In addition, building density (a measure of human influence) was positively related to DIC export, whereas wetlands were positively related to DOC export. Finally, the presence of lakes in the catchment had a negative effect on DOC export but none on DIC export. Variables describing geology (as either general rock formation or surface material type) and soil type did not contribute significantly to predicting C export. As mentioned in Section 2.4, %forest and %pasture were not offered in the step-wise model-building process, because of their strong correlation with %vegetation.

Table 2. Multiple linear regression models predicting DIC, DOC, and TC export in g m^{-2} yr^{-1} (n=83 for each). Estimates of coefficients and corresponding p values are given for all variables offered during the step-wise selection process. Variables were included in the model if $p<0.05$ (in bold) and the corresponding R^2 values are shown.

	Parameter	DIC		DOC		TC	
		Estimate	p value	Estimate	P value	Estimate	p value
Topography	Catchment area (km^2)*	1.069	**<0.0001**	0.672	**0.0323**	1.412	**0.0002**
	Average elevation (m)		0.7584		0.2181		0.6454
	Average slope (°)		0.2418	- 0.271	**0.0041**	- 0.266	**0.0066**
	BSI	- 2.088	**0.0201**	2.705	**0.0068**		0.8220
Land cover	%vegetation	- 0.038	**0.0017**	0.061	**0.0003**		0.5486
	%wetland		0.8931	0.530	**<0.0001**	0.690	**<0.0001**
	%lake		0.3783	- 0.139	**0.0002**		0.0601
	Buildings per km^2	0.036	**0.0116**		0.4498		0.8632
	Intercept	9.914	**<0.0001**	- 3.423	0.1072	9.731	**<0.0001**
R^2		0.34		0.62		0.53	

* Catchment area is log10 transformed.

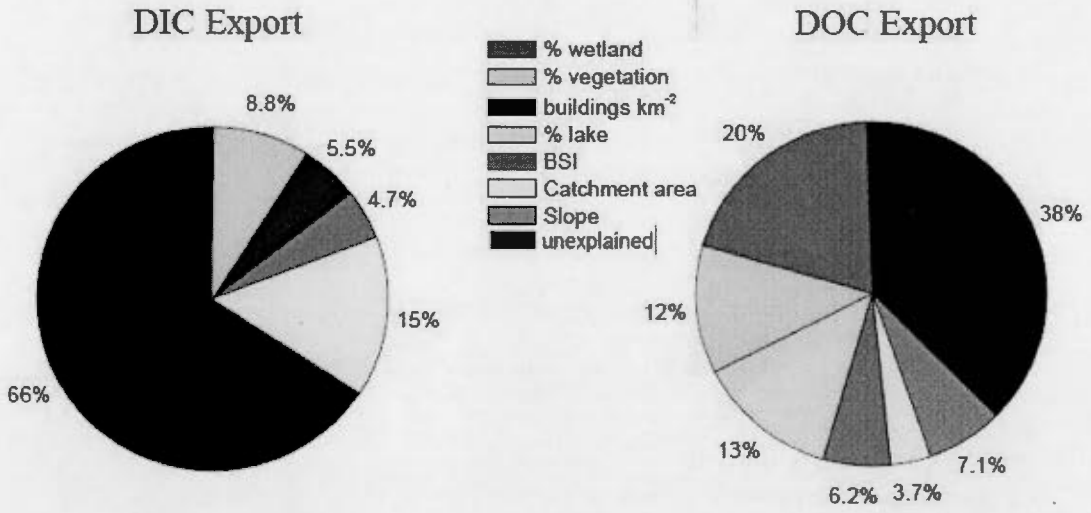

Figure 4. Variance partitioning in the multiple linear regression models of DIC and DOC export, showing the percentage of variability explained by each component variable and the remaining variability, unexplained by the models.

Figure 4. Variance partitioning in the multiple linear regression models of DIC and DOC export, showing the percentage of variability explained by each component variable and the remaining variability, unexplained by the models.

An examination of the sums of squares associated to each variable in the multiple regression models allows us to determine the relative influence of topographical and land cover variables on C export (Figure 4). The topographical variables (catchment area and BSI) were slightly more important than the land cover variables (%vegetation and building density) in predicting DIC export, with topography and land cover explaining 19% and 15% of the variability, respectively. In contrast, land cover variables (%vegetation, %wetland and %lake) were more important than the topographical variables (catchment area, BSI and slope) in predicting DOC export, land cover and topography explaining 44% and only 18% of the variability in the DOC model, respectively. In terms of TC export, the topographical variables (catchment area and slope) and land cover (%wetland) explained roughly the same amount of variation (24% versus 29%, respectively).

The positive relationship of catchment size with both DIC and DOC exports resulted in an overall positive effect of catchment size on TC export (Table 2). In contrast, the opposing effects of BSI and %vegetation on DIC and DOC export canceled each other out and as a result, these variables had no overall impact on TC export. The positive effect of %wetland and the negative effect of slope on DOC export were strong enough to influence overall TC export, despite their lack of influence on DIC export.

1.4.3 Inter-annual variation in carbon export

The preceding results were based on the average C export for 83 basins in 2004 and 2005; however, we also examined inter-annual variation in C export from 2003 to 2005 for a subset of 32 basins. Continuous measurements from 13 weather stations in the study area reveal that 2005 was the warmest and wettest year, with 1°C higher respectively (ANOVA, $R^2 = 0.59$, $p<0.0001$, $n = 96$, Tukey-Kramer $p<0.0001$) (Figure 5). DOC exports were also significantly higher in 2005 than in 2004 and 2003, with average DOC exports for the 32 basins of 6.1, 5.0, and 5.2 g m^{-2} yr^{-1} in 2005, 2004, and 2003, respectively (ANOVA, $R^2 = 0.31$, $p<0.0001$, $n = 96$, Tukey-Kramer $p<0.0001$) (Figure 5). As a consequence, TC exports were also significantly higher in 2005 than in 2004 and in 2003, with average TC exports for the 32 basins of 13.6, 10.7, and 11.0 g m^{-2} yr^{-1} in 2005, 2004, and 2003, respectively (ANOVA, $R^2 = 0.67$, $p<0.0001$, $n = 96$, Tukey-Kramer $p<0.0001$). There was no inter-annual difference between exports in 2003 and 2004 for any C species.

Table 3. Local climate, gauged daily discharge, as well as discharge and DIC and DOC concentrations measured in situ at the 32 sites in 2003, 2004 and 2005.

	2003	2004	2005
Annual mean air temperature (°C) [a]	5.0	5.1	6.0
Annual precipitation (mm) [a]	1245	1026	1316
Mean (SD) of mean daily discharges at Trois-Lacs ($m^3 s^{-1}$) [b]	13.4 (18.7)	12.7 (15.9)	15.6 (23.9)
Mean (SD) of mean daily discharges at Waterloo ($m^3 s^{-1}$) [c]	0.57 (0.77)	0.62 (0.81)	0.68 (0.97)
Mean (SD) measured in situ discharge ($m^3 s^{-1}$)	NA	0.30 (0.59)	0.59 (1.4)
Mean (SD) DIC concentration (mg L^{-1})	8.7 (4.0)	8.9 (4.7)	9.8 (5.4)
Mean (SD) DOC concentration (mg L^{-1})	8.3 (3.7)	8.2 (4.0)	8.7 (4.7)

[a] Data from http://climate.weatheroffice.gc.ca

[b] Data from https://www.cehq.gouv.qc.ca/suivihydro/graphique.asp?NoStation=030101

[c] Data from https://www.cehq.gouv.qc.ca/suivihydro/graphique.asp?NoStation=030343

1.5 Discussion

The C exports and DIC/DOC export ratios that we measured for these 83 basins in southern Québec are well within the range of values found in the literature. Our range of DOC export (1.1 to 13 g m^{-2} yr^{-1}) is in very good agreement with that estimated by *Eckhardt and Moore* (1990) in roughly the same area (1 to 18 g m^{-2} yr^{-1}). The average DOC export of 5.1 g m^{-2} yr^{-1} corresponds to the mid-range of DOC exports reported for Atlantic Canada (1.6 to 12.4 g m^{-2} yr^{-1}) (*Clair et al.*, 1994), for forested landscapes in southeastern Canada (0.9 to 13.7 g m^{-2} yr^{-1}) (*Creed et al.*, 2008), or for forested watersheds in other temperate regions of North America (0.3 to 41.7 g m^{-2} yr^{-1}) (*Hope*

et al., 1994), and very similar to the average DOC export of the 6 g m^{-2} yr^{-1} reported for wet temperate regions by *Meybeck* (1993). Similarly, our DIC export range of 1.1 to 11 g m^{-2} yr^{-1}, and average of 4.6 g m^{-2} yr^{-1}, were well within the range of riverine exports found in Europe (0.5 to 67.8 g m^{-2} yr^{-1}) (*Hope et al.*, 1994), although they were slightly higher than those found in Atlantic Canada (0.04 to 4.19 g m^{-2} yr^{-1}, average 0.71 g m^{-2} yr^{-1}) (*Clair et al.*, 1994) and were much higher than those found in central Ontario (0.81 to 1.69 g m^{-2} yr^{-1}, average 1.12 g m^{-2} yr^{-1}) (*Dillon and Molot*, 1997). As for TC export, our range of 2.5 to 18 g m^{-2} yr^{-1} and average of 10 g m^{-2} yr^{-1} agree well with TC export from north Atlantic rivers in the United States (3.7 to 15 g m^{-2} yr^{-1}, average of 7.2 g m^{-2} yr^{-1}) (*Stets and Striegl*, 2012), but is lower than TC exports from European rivers at similar latitudes (e.g. TC exports for the Adige, Danube and Po Rivers, which were 16.7, 12.4 and 30.1 g m^{-2} yr^{-1}, respectively) (*UNEP*, 2003).

The decoupling between DIC and DOC exports that we observed in our systems (Fig 1) has also been observed in other regions, leading to variations in DIC/DOC export ratios both within and across regions. In this regard, our DIC/DOC export ratio varied widely across catchments (from 0.2 to 3.9), and the overall mean of 1.14 was much higher than published DIC/DOC ratios in Atlantic Canada (0.01 to 0.86, average 0.13) (*Clair et al.*, 1994) and central Ontario (0.13 to 0.32, average 0.27) (*Dillon and Molot*, 1997). This inter-regional difference is largely attributable to differences in the amount of wetlands and carbonate rocks, which relate to the production of soil DOC and DIC, respectively. Atlantic Canada and central Ontario are lithologically dominated by volcanic and granitic rocks, respectively, whereas most of our study area, is underlain by carbonaceous sedimentary rocks (*Paradis and Lavoie*, 1996), which contribute more DIC by weathering. In addition, most of the catchments

studied in Atlantic Canada, are located on islands, where the soils are poorly developed, thereby producing less DIC from soil respiration. Furthermore, the study area in central Ontario has more wetlands (up to 25%) than ours (up to 9%), which contribute more DOC and further lower the DIC/DOC ratio.

We designed this study to maximize spatial coverage and environmental gradients, while still capturing at least some of the seasonal variability in riverine discharge and C concentration. Discharge is without doubt the most variable of these two components, but we were able to reconstruct the annual discharge pattern by relating our point measurements to a continuous discharge record in one of study streams (n>600 point measurements). This approach is effective to capture both the total runoff from each stream and the main features of the annual hydrographs. With regard to the temporal variability in C concentrations, we examined the mean-variance relationship for DIC and DOC concentrations, by plotting the variance of all concentration measurements at a given site in a given year, V, versus the mean concentration for that site in that year, X. Combining the 32 sites sampled in 2003 with the 83 sites sampled in 2004 and 2005, there were a total of 198 site-years for which we could compare the variance to the mean. Applying the resulting mean-variance equations ($V_{DIC}=0.032*X_{DIC}^{2.49}$, $R^2=0.51$, $p<0.0001$, $n=198$; $V_{DOC}=0.019*X_{DOC}^{2.62}$, $R^2=0.67$, $p<0.0001$, $n=198$) following *Cattaneo and Prairie* (1995) allowed us to determine that no more than 4 samples per year were required to obtain a mean concentration for a given site with a precision of 20%. As we visited each site 4-7 times per year, the mean concentration calculated for any site should have an error of 20% or less, thereby confirming the adequacy of our sampling strategy. Carbon concentrations are less temporally variable than nutrients such as N and P (*Moatar and Meybeck*, 2007; *Birgand et al.*, 2011), and a similar precision was

obtained by *Birgand et al.* (2011) for total dissolved carbon sampled monthly in a forested catchment. With our experimental design, we found more variability in carbon export among sites than within a year at a single site, which allowed us to explore the drivers of carbon export across catchments of differing topographical and land cover characteristics.

1.5.1 Drivers of Terrestrial Carbon Export to Aquatic Systems

While topography and land cover together explained only 34% of the variability in DIC export, they explained 62% of the variability in DOC export, clearly illustrating that DIC and DOC export are controlled by different biogeochemical processes. Furthermore, whereas land cover and topography were equally important in determining DIC export (explaining 15% and 19% of the variability, respectively), land cover was clearly a stronger driver of DOC export than was topography (explaining 44% and 18% of the variability, respectively). These results support our hypothesis that a combination of underlying topographical features and potentially more dynamic land cover features are involved in determining the various forms of C exported.

Despite these differences, there was one driver that was common to all forms of C export, whether DIC, DOC, or TC: catchment area was positively related to all forms of C export, either alone (Figure 2), or in combination with other effects in multiple linear regression models, explaining 15%, 4% and 16% of the variability in DIC, DOC, and TC export, respectively (Table 2, Figure 4). This is in contrast to the finding of *Ågren et al.* (2007) that small headwater catchments export the most terrestrial DOC, in a comparison of 15 sub-catchments in Sweden ranging in size from 0.03 to 22 km^2. It is difficult to explain why catchment area should play a role in

how much C is exported per square kilometer. We found no significant relationship between carbon concentration (DIC, DOC, or TC) and catchment area ($p>0.05$, $n=83$, using the average of 2004 and 2005 concentrations for each site and using either terrestrial or total catchment area). This is inconsistent with the positive relationship with DOC concentration reported by *Inamdar and Mitchell* (2006) and the negative relationship with DOC concentration reported by *Wolock et al.* (1997). Thus, the ultimate driver is likely hydrology, and in this regard, we find a relatively strong positive relationship between catchment size and runoff (parameters), and also with catchment elevation. The reasons underlying this positive relartionship are not clear, but could be related to shifts in land cover patterns with catchment size. In particular, there was a trend for larger catchments to have less forest and vegetation cover and higher proportion of agricultural lands, and it has been suggested that runoff actually increases with deforestation and human-induced landscape alternations (*Allan*, 2004; *Maetens et al.*, 2012).

1.5.1.1 Drivers of DIC Export

After catchment area, %vegetation in the watershed was the second most important factor determining DIC export, with less vegetated basins exporting more DIC. This agrees with previous work that has shown that deforestation or conversion of natural vegetation into pasture increases DIC export from the landscape, either when comparing DIC export across basins (*Baker et al.*, 2008; *Rantakari and Kortelainen*, 2008; *Regnier et al.*, 2013) or when following DIC export within a basin as its land cover changes over time (*Raymond and Cole*, 2003; *Yan et al.*, 2013). There are several processes that can explain the observed pattern between %vegetation and DIC export. In our study region, unvegetated areas often corresponded to pasturelands which, in comparison with forest soils, tend to have higher soil respiration rates

(*Smith and Johnson*, 2004; *Kellman et al.* 2007), leading to elevated soil CO_2 and greater weathering potential (*Likens*, 2010; *Bayon et al.*, 2012). Previous studies have shown that replacing forest species with forage or farm crops results in a decrease in the soil C/N ratio, leading to a more rapid mineralization of soil organic matter and litterfall, thus increasing groundwater DIC and soil CO_2 (*Marland et al.*, 2004; *Hedley et al.*, 2009). Moreover, deforestation, due to agriculture or pasture, can intensify weathering (*Likens*, 2010; *Bayon et al.*, 2012), thus releasing more bicarbonate and carbonate ions into river water. Therefore reducing the vegetation coverage and/or shifting land uses to agricultural or residential may increase DIC export by increasing soil respiration rates and weathering.

In addition, C geochemistry and water chemistry in river systems are dependent largely on lithological variability in carbonate/silicate-dominated terrains (*Amiotte-Suchet et al.*, 2003; *Zhang et al.*, 2009). Our study area is located in the transition region between the Humber and Dunnage Zones, underlain by carbonate-rich and non-calcareous siliceous sedimentary rocks and mafic volcanic rocks associated marine sediments, respectively. Particularly, in the Humber zone there are the world's largest asbestos mine, and several talc mines (*Castonguay and Tremblay*, 2003), both of which are hydrous magnesium silicates that are often associated with carbonates and easily hydrolyzed to release HCO_3^-. The fact that 9 of the 10 catchments with DIC export of more than 6.6 g m^{-2} yr^{-1} are in the Humber Zone (except the stream outflowing Lake Nick), further highlights the importance of carbonate and silicate rocks in controlling riverine DIC export from the catchment. DIC export also increased with building density. Buildings and their residents are not point sources of DIC but higher building density usually results in land clearing and road construction, causing an anthropogenic increase in erosion and therefore DIC

export from soils. This positive effect is strongly supported by previous studies (*Daniel et al.*, 2002; *Barnes and Raymond*, 2009; *Zeng et al.*, 2011).

Basin shape index, BSI, also played a significant role in controlling DIC export. The greater the departure from a circular basin (BSI>1.0), the less DIC that is exported. This negative relationship may be due to hydrological pathways being more convoluted in basins with more complex shapes. For example, circular catchments are more prone to flooding than elongated ones (*Waugh*, 1995; *Rasool et al.*, 2011), leading to higher erosion and flushing out of various forms of terrestrial DIC.

1.5.1.2 Drivers of DOC Export

The two variables that explained most of the variation in DOC export were %lake and %wetland. Basins containing more lakes exported less DOC, which highlights the role of lakes as sinks of terrestrially-derived organic matter (*Larson et al.*, 2007). Temperate and boreal lakes accumulate large amounts of terrestrial C in their sediments (*Ferland et al.* 2012; *Tranvik et al.* 2009), and also decompose and emit a portion of this terrestrial DOC as CO_2 and CH_4 (*Larson et al.*, 2007; Dinsmore *et al.*, 2013). Although the catchments in this study did not contain many wetlands (maximum 9% coverage), wetlands still played a role in shaping DOC export, as has been reported for other regions (*Eckhardt and Moore*, 1990; *Dillon and Molot*, 1997; *Huntington and Aiken*, 2013). These two land cover variables are susceptible to anthropogenic and climate change through drainage, damming, and changes in the hydrologic regime. Therefore changes to the amount and extent of wetlands and lakes in a watershed will affect two important sources and sinks of DOC and thus the movement of terrestrial C into the aquatic system and the atmosphere.

We found that DOC export was also correlated with %vegetation and BSI, but the direction of the correlation was opposite of that for DIC export, highlighting the independent nature of DOC and DIC exports (Figures 1 and 3). Although the presence of vegetation lowered DIC export, it increased DOC export in these basins, which agrees with previous work (*Meyer and Tate, 1983*; *France et al., 1996*). The positive relationship between DOC export and %vegetation reflects the fact that most riverine DOC is ultimately derived from land vegetation (via direct litter input and leaching) and soils (via microbial activity, root exudation, leaching and erosion of organic matter) (*Spitzy and Leenheer*, 1991). The influence of BSI on DOC export was opposite to that on DIC export, with elongated more complex high BSI basins exporting more DOC than round, less complex low BSI basins. Similarly, *Pacific et al.* (2010) showed that a more elongated basin often has a higher ratio of riparian to upland area and can export more DOC to river systems. As mentioned above, that larger catchments exported more C, but in this region, larger watersheds were also characterized as having a lower average slope (R^2=0.17, p=0.0001, n=83) and lower average elevation (R^2=0.08, p=0.0080, n=83), although these correlations are weak. Once entered into a multiple regression with catchment area as a factor, elevation had no effect on C export; however, watersheds with a flatter average slope exported more DOC and TC, independent of the effect of catchment size. Gentler slopes facilitate wetland formation, leading to more DOC production and export (*D'Arcy and Carignan*, 1997), and also have longer water residence times, allowing more time for soil DOC to leach into soil water and neighboring waterways (*Hazlett et al.*, 2008; *deCatanzaro and Chow-Fraser*, 2011).

1.5.1.3 Drivers of TC Export

We were able to explain 53% of the variation in total C export using two topographical variables, catchment area and slope, and one land cover variable, %wetland. The positive effect of catchment area on both DIC and DOC exports results in a similar influence on TC export, likely through its effect on discharge, as discussed above. The negative effect of slope on DOC was strong enough to result in a negative effect on TC export, explaining 8% of its variability, despite the lack of a relationship between slope and DIC export. Similarly, the effect of increasing TC export with increasing wetland coverage arose solely because of the important role of wetlands in controlling DOC export, as wetlands did not play a role in DIC export. This land cover feature of the catchment explained 29% of the variability in TC export. In contrast, although BSI and %vegetation played important roles in both DIC and DOC exports, they acted in opposite directions on the two C species, and as a result, had no overall impact on TC export. As we observed for DIC and DOC export, TC export is influenced by a combination of topographic and land cover effects, explaining 24% and 29% of its variability, respectively. Because the drivers of DIC export and DOC export are quite different, the model of TC export provides a simplified summary of what influences the movement of terrestrial C to aquatic systems, while hiding the complexity of what influences the movement of individual C species.

Despite there being evidence in the literature for the effect of soil type and geology on C export, these factors did not emerge as significant drivers in our watersheds. We used maps of geology and soil to divide the catchments, based on areal percentages (Table 1), into 3 mutually exclusive categories of rock type (intrusive, sedimentary and volcanic) as well as 3 mutually exclusive categories of surficial deposits (rock, till and mud) and 5 mutually exclusive categories of soil (brunisolic, gleysolic,

regosolic, podzolic and organic). We found one potential model of DIC export that incorporated the percent coverage of sedimentary rocks and rocky surficial deposits but it is unclear why DIC export would decline with increasing presence of sedimentary rocks and rocky surficial deposits. In addition to explaining only a marginal 4% more of the variability in DIC export than the model in Table 2, it required removing BSI as an effect and removing one outlier site, and so this model was considered less appropriate for these catchments. There were no potential models for DOC or TC export that incorporated geology or soil. In summary, we did not find that geology or soil type played very important roles in controlling DIC, DOC and TC export from the landscape.

1.5.2 Influence of Land Cover on the Forms of Carbon Exported

Although vegetation coverage did not play a significant role in total C export, it did have an impact on the actual nature of this export. We used the models in Table 2 to project total C export and its partition into DIC and DOC exports, under scenarios of changing land use in terms of %vegetation, for two of our basins (Figure 6). In the case of the basin that drains into Lac d'Argent, which currently has 92% vegetation coverage, reducing the vegetation coverage to 40%, for example due to agriculture or urbanization, would result in an 11% decrease in C export from the basin (as DIC+DOC) (our test using DIC+DOC, instead of DIC+1.1*DOC, as TC export showed the same result although the coefficients are slightly different), but a 3-fold increase in the DIC/DOC export ratio, from 0.8 to 2.2. The reduction in vegetation coverage would thus cause a shift in this basin from a system that exports most of its terrestrial C as DOC, to a basin that exports mostly DIC. Conversely, for an inflow of Roxton Pond, which currently drains a watershed that is 57% vegetated, increasing the vegetation coverage to 100% would result in only a 9% increase in C export,

while the DIC/DOC export ratio would be reduced to half, from 1.1 to 0.5 (Figure 6). In this case the watershed would shift from exporting equal amounts of DIC and DOC to exporting mainly DOC. Land use change that modifies vegetation coverage, such as deforestation or reforestation, would therefore have a modest effect on total C export, but would greatly alter the form of C exported. Although deforestation is widely regarded as one of the most common anthropogenically-driven land cover changes, especially in developing countries (*Nagendra*, 2007), many of the temperate regions in Eastern North America and Western Europe have been undergoing reforestation due to a decline in agriculture (*Rudel*, 1998; *IPCC*, 2013). As DOC and DIC are processed differently in aquatic systems, changes in the form of terrestrial C exported will lead to changes in the fate of this C, with DOC being more likely to be mineralized and released to the atmosphere as CO_2 and CH_4 than DIC, which may be transported downstream in a more conservative manner. To summarize, reductions in vegetation coverage will shift the C export to favor the inorganic rather than the organic forms of C, potentially leading to the terrestrial C being transported further downstream, rather than being released to the atmosphere through biological processes in the aquatic system.

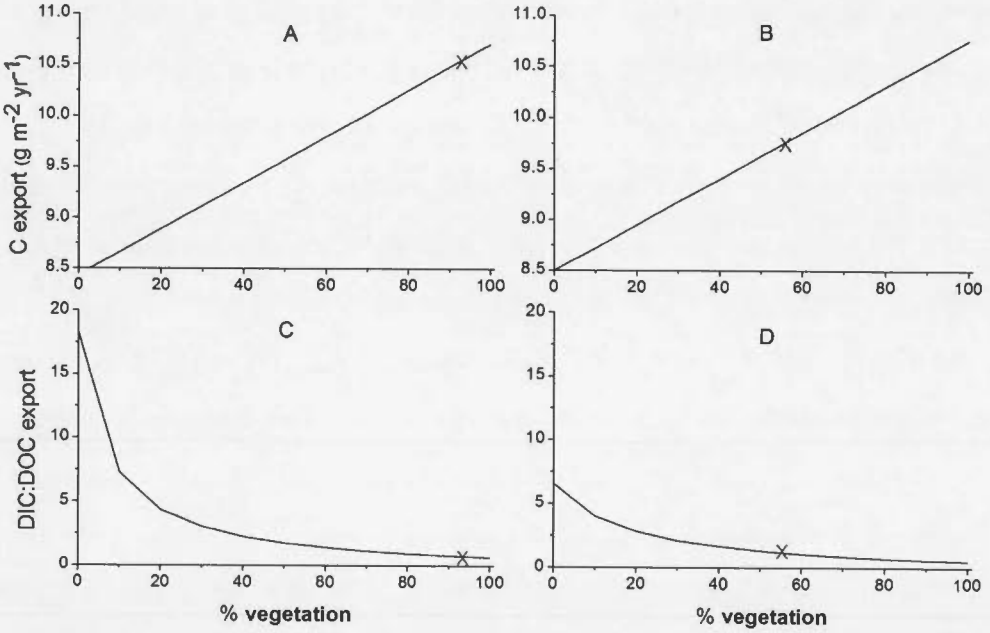

Figure 6. Carbon export as the sum of DIC export and DOC export in g m^{-2} yr^{-1} and the DIC/DOC export ratio versus %vegetation for two example watersheds, an inflow to Lac d'Argent (panels A and C) and an inflow to Roxton Pond (panels B and D). The current vegetation coverage of the catchment is indicated by an "X" in each panel.

1.5.3 Inter-annual Variation in Carbon Export

The differences in C export observed in 32 basins over 3 consecutive years were likely driven by inter-annual variations in temperature and precipitation, causing inter-annual variations in stream discharge (Table 3). Export of both DIC and DOC was about 25% higher in 2005 (at 6.8 and 6.1 g m^{-2} yr^{-1}, respectively) relative to 2003 and 2004 exports (Figure 5). In terms of temperature and precipitation, 2005 was a warm, wet year and 2004 a dry year, as compared to a relatively average 2003. This resulted in the mean daily discharge at the Trois-Lacs gauged site being higher and more variable in 2005 than in the two preceding years (ANOVA p=0.0063, n=1096, 2003=A, 2004=AB, 2005=B). Similarly, at the Waterloo gauged site, mean daily

discharge was higher and more variable in 2005 (ANOVA p=0.0004, n=1096, 2003=A, 2004=B, 2005=B). Discharge was therefore significantly higher in 2005 than in 2003, and this likely drove the differences in C export, a pattern that has been previously reported (*Dillon and Molot*, 2005; *Dinsmore et al.*, 2013). As C export is the product of discharge and C concentration per unit catchment area, we also examined inter-annual variability in concentration. Average DIC and DOC concentrations were highest in 2005 (Table 3), yet there were no significant differences in concentration among years. In other words, variation in C concentration across the 32 sites was more important than variation across the 3 years. Interestingly, at the scale of the individual site, we found a negative effect of discharge on DIC concentration within 31 of our 83 sites (dilution effects, outlined in Section 2.2), yet at the regional scale, the highest discharge year (2005) was associated to the highest average DIC concentrations, and the highest average DIC export from all sites combined. We suggest that transient increases in runoff and discharge within a catchment may not necessarily lead to increased DIC release from soils, and this may explain the local dilution effects that we sometimes observed. However, a systematic increase in overall precipitation and temperature, and the associated sustained increased in runoff and discharge, may act to increase overall DIC and DOC export on an annual scale.

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CHAPTER II

MAGNITUDE AND COMPOSITION OF CARBON EXPORTED FROM BOREAL CATCHMENTS TO RIVER SYSTEMS IN NORTHERN QUÉBEC, CANADA

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N.B. References cited in this chapter are presented at the end of the thesis.

2.1 Abstract

Rivers play a major role in regional and global carbon (C) cycling by channeling and processing large amount of C that is derived from land. The form of the C exported from watersheds to fluvial systems determines the biogeochemical role and fate of this C, yet few studies have simultaneously assessed the major forms of C exported from land to rivers. Here we have quantified river-mediated export of dissolved organic and inorganic C (DOC and DIC), as well as the integrated aquatic emissions of both CO_2 and CH_4, from 44 boreal catchments that range widely in size, topography and land cover. Our results show that DOC and DIC exports averaged 9.1±.3 and 2.8±1.9 g C m^{-2} (catchment) yr^{-1}, respectively, whereas total aquatic CO_2 and CH_4 emissions averaged 3.1±3.6 and 0.1±0.1 g C yr^{-1} per m^2 catchment, respectively. The resulting total C (TC) export was seasonally very variable, driven

mostly by the annual runoff cycle, and averaged 15.6±5.3 g C m^{-2} yr^{-1}. DOC dominated on average this TC export over the annual cycle (59%), but aquatic CO_2 emissions were a major component of TC export in all catchments (average 20%). Our results confirm that DOC and DIC exports are mostly driven by runoff but further regulated by fundamentally different environmental factors, and that wetlands are a major source of DOC exported to rivers, but further demonstrate that lakes within the catchment are a strong DOC sink, such that the net export of DOC results from the balance between them. CO_2 emissions replace DOC export as the main lateral C export with increasing water coverage in the catchment. The annual TC exported via rivers is within the range of net ecosystem production (NEP) that has been estimated for these boreal landscapes, but it is it still unclear what components of this total riverine export, if any, may be included in these NEP estimates. Regardless, this river-mediated lateral loss of C has the potential to fundamentally alter our perception of the role of these boreal landscapes as sources or sinks of atmospheric CO_2.

Key words Riverine carbon; DOC; DIC; greenhouse gases; boreal catchments; carbon cycle.

2.2 Introduction

Rivers are a fundamental component of the global C cycle, processing C that originates in the terrestrial biosphere, transporting it to the oceans and returning it to the atmosphere. It is now recognized that a sizable fraction of watershed terrestrial net primary productivity (NPP) is channeled to rivers, but whereas there is a relatively strong consensus that the total amount of C delivered to the oceans by rivers worldwide is in the range of 0.9 Pg C y^{-1} (*Meybeck*, 1982; *Cole et al.*, 2007);

there is still much uncertainty regarding how much C is actually exported from land to rivers. It is now recognized that there is a significant but variable amount of processing of inorganic and especially organic C of terrestrial origin during transit within river networks (*Cole et al.,* 2007), such that the amounts of C reaching the ocean do not necessarily reflect the C that was originally exported from land. In fact, the estimates of C export from land to rivers have systematically increased over the past decade, to current estimates that are in the order 2.5 to 3.1 Pg C annually (*Tranvik et al.,* 2009; *Battin et al.,* 2009), and so have the estimates of the portion of this C that is buried in aquatic sediments, and returned to the atmosphere as CO_2. It is clear that there is still much uncertainty concerning not only the magnitude but also the regulation of these components of the global C cycle.

The form of the C exported from watersheds to fluvial systems is key not only to the functioning of these aquatic aquatic ecosystems, but to the actual biogeochemical fate of this C in the landscape. For example, whereas DIC exported from soils tends to transit through aquatic networks with relatively little alteration, DOC tends to be transformed and degraded through biological and photochemical processes, fueling in situ metabolism in the receiving systems, and further fueling CO_2 and CH_4 emissions from these ecosystems. Soil-derived CO_2 and CH_4, on the other hand, will tend to flux out to the atmosphere, although a portion will also be transported downstream together with the DOC and DIC. Over the past decade, there has been increasing interest and research seeking to establish the magnitude and the regulation of each of these components of river C dynamics. For example, studies have identified the main factors driving DOC export to rivers, including regional precipitation (*Clair et al.,* 1994; *Dinsmore et al.,* 2013), runoff (*Brinson,* 1976; *Raymond et al.*, 2007), land use (*Barnes and Raymond*, 2009; *Regnier et al.,* 2013), catchment slope (*Eckhardt and*

Moore, 1990; *Dosskey and Bertsch,* 1994; *Hazlett et al.*, 2008; Li et al., 2015), soil C:N ratio (*Aitkenhead and McDowell*, 2000), pH (*Brooks et al.,* 1999), and the density of lake and wetland systems in the catchments (*Koprivnjak and Moore*, 1992; *Dillon and Molot,* 1997; *Ferland et al.,* 2012).

Dissolved inorganic C (DIC), on the other hand, appears to be strongly influenced by catchment geology, in particular by the presence of carbonate deposits in the catchment (*Liu et al.,* 2000; *Zhang et al.,* 2009; *Tank et al.,* 2012), and topographical position and basin elevation (*Soranno et al.,* 1999; *Kling et al.,* 2000; *Finlay et al.,* 2010; *Li et al.,* 2015). Others have shown that land cover change affects DIC export. For example, the reduction of natural vegetation due to logging, farming, pasturing or urbanizing are all believed to increase riverine DIC export (*Daniel et al.,* 2002; *Raymond and Cole,* 2003; *Baker et al.,* 2008; *Barnes and Raymond,* 2009; *Regnier et al.,* 2013; *Li et al., 2015*). Further, it has been known for decades that most streams and rivers are supersaturated with CO_2 (*Kling et al.,* 1991; *Cole et al.,* 1994), and CH_4 (*Billett and Moore,* 2008; *Bastviken et al.,* 2011; *Campeau et al.*, 2014), but the evasion of CO_2 and CH_4 from river systems has only recently been recognized as an important regional source of atmospheric greenhouse gases (GHG) (*Butman & Raymond,* 2011; *Bastviken et al.,* 2011; *Raymond et al.,* 2013; *Campeau et al.,* 2014), and the number of studies focusing on river C gas evasion has increased exponentially in recent years.

One of the main patterns to emerge from this collective body of work is the fact that the various forms of riverine C (DIC and DOC export, CO_2 and CH_4 transport and emission) are regulated very differently from each other, and that therefore the controls of total C export from land to rivers, and the fate of this C are more complex

than what were originally thought. One of the main challenges that still remains in order to resolve this complexity is that the data on C export is still fragmented and lacking integration, since most studies to date have focused on a specific C species (*Mulholland and Watts,* 1982; *Hope et al.,* 1994; *Alvarez-Cobelas et al.,* 2012; *Hossler and Bauer,* 2013), and in a limited range of watershed types. Very few studies to date have simultaneously quantified all the main components that make up the total pool of C that is exported from land to rivers (*Billett and Moore,* 2008; *Polsenaere et al.,* 2013; *Striegl et al.,* 2012; *Abril et al.*, 2000), and fewer still have done this across a range of environmental, geographic and climatic gradients (*Butman and Raymond,* 2011; *Stets and Striegl,* 2012).

In this study we have explicitly assessed the magnitude, composition and regulation of total C export from a wide range of catchments that are located in the boreal region of Québec. The boreal biome represents one of the largest C pool on the earth, where a large proportion of all terrestrial organic C is stored in soils and in peatlands (*Molot and Dillon,* 1996). It is also a landscape with among the highest density of surface waters in the world, and where freshwaters are more likely to play a key role in terms of regional C processing and transport. The specific objectives of this study were: 1) to quantify the dynamics of DOC, DIC, CO_2 and CH_4 across a wide range of rivers in the boreal region of Québec; 2) to reconstruct the magnitude of total C export from these boreal watersheds; and 3) to explore how the magnitude and composition of this total C export to rivers varies across catchments and along environmental, geographic and climatic gradients.

2. 3 Materials and methods

2.3.1 Study area

Our general study area is located in the lowland region of northern Québec, Canada, within the Northern Clay Belt, which was created by lacustrine deposits from the proglacial lakes Barlow and Ojibway. The rivers we sampled and their respective catchments are located in two distinct sub-regions: South Abitibi (47–48°N, 78–79°W) and James Bay (48–49°N, 78–79°W). Geologically, this area is located in the Abitibi sub-province of Canadian Shield. The bedrock is composed of granitoid (50%), volcanic (40%), and sedimentary (10%) rocks formed *ca.* 2.7 billion years ago and covered by a thin layer of soil (Asselin et al. 2006). The James Bay region is located within the black spruce – feather moss bioclimatic domain, and is characterized by extensive peat bogs and fens, whereas South Abitibi is within the balsam fir (*Abies balsamea L. Mill.*) – paper birch (*Betula papyrifera Marsh*) bioclimatic domain, and has much less coverage of peat bogs (Bergeron et al., 2004). From south to north across the study area, mean annual temperature varies from 0 to 1.7 °C, and mean annual precipitation from 880 to 975 mm (Asselin et al. 2006). Beaver dams are ubiquitous throughout South Abitibi, especially along 1st to 3rd order streams, while they are practically absent in James Bay, which is dominated by peatlands. Further details of the sites and of the sampling regime can be found in Campeau et al., (2014).

The CO_2 and CH_4 dynamics and fluxes to the atmosphere in these boreal rivers have been previously reported by Campeau et al. (2014) and Campeau and del Giorgio (2014). Here we combine these previous results on gas dynamics with additional data on DOC and DIC concentrations and river discharge to assess the magnitude of C export from these boreal catchments, and in particular to derive estimates of total watershed C export that include not only DIC and DOC transport by rivers, but also C gas emissions by both rivers and lakes within these catchments.

2.3.2 Sampling and chemical analyses

In this study we use data collected from 44 sites, 30 located in South Abitibi and 14 located in James Bay, ranging from Strahler Order 1 to 7. Thirteen of these rivers were visited 8 times each from May 2010 to May 2011, at around 5 week intervals, 20 were visited three times between May and October 2010, and 11 were visited once in mid-summer 2010. Water was sampled approximately 10 cm below the water surface and filtered in situ using 0.45 μm syringe filters and then sealed, refrigerated and transported to the lab in 40 mL glass vials (I-CHEM) for chemical analyses. Concentrations of DIC and DOC were determined following acidification and oxidation with phosphoric acid and sodium persulfate, respectively, using a TOC1010 total carbon analyzer, equipped with an infrared CO_2 detector (OI Analytical, 2% precision of 2 replicates per vial, 3% accuracy at 5 mg L^{-1} standard).

2.3.3 Discharge and DOC and DIC flux calculations

Carbon export of each stream was calculated as the product of the water loading and the water C concentration (mg L^{-1}), and therefore it is essential to accurately determine both components. During the study period, we had pressure sensors (True-Tracks) installed in four additional rivers and streams for continuous monitoring of river water level. For each of these streams we developed an empirical discharge/water level relationship based on the channel morphometry, which we used to estimate the daily discharge of each of these 4 rivers. In addition, the daily discharges of Harricana and Kinojévis rivers were obtained directly from the government-operated continuous gauging stations (hydrologic stations: 043012 and 080101) (http://www.mddelcc.gouv.qc.ca). Based these 6 sampled streams and rivers, we obtained an average daily runoff (mm d^{-1}) curve for the entire water year (Figure

1a), and this average regional curve was then used as the local runoff pattern to estimate daily discharge of all the sampled rivers based on their respective watershed areas. There was good overall agreement between the discharge estimated this way, and the actual measured discharge in our point sampling across all of our rivers (R^2=0.84, n=113, p<0.0001) (Figure 1b).

We measured DOC and DIC concentrations at each sampling date, and these concentrations need to be extrapolated in time in order to calculate daily export. Previous studies have shown that there may be both concentration and dilution effects related to shifts in discharge (Li et al., 2015). We explored this possibility by assessing the concentration versus discharge relationships of all the individual streams using ANCOVA, and testing the significance of the resulting slopes. The results show that the daily runoff had a significant overall negative (dilution) effect on DIC concentration (R^2=0.62, RMSE=0.2481, n=165, p<0.0001), and a significant positive (concentration) effect on DOC concentration (R^2=0.68, RMSE=0.151, n=169, p<0.0001). We used the resulting slopes and the river-specific DOC or DIC intercept offset to correct for discharge-related shifts in DOC and DIC concentration for each river. Daily C export was then calculated as the product of daily runoff and daily C (DOC and DIC) concentration, and annual DIC and DOC export was calculated as the sum of daily export values for the whole water year. River POC concentrations were not measured and therefore POC flux had to be approximated, which we did by assuming POC roughly equal to 5% TOC for boreal forest eco-region (Ivarsson and Jansson 1994; Hope et al. 1994). PIC flux was not included in the TC exported from the catchments because previous studies have shown that it accounts for a very small fraction of inorganic C (Aucour et al. 1999; Hossler and Bauer 2013).

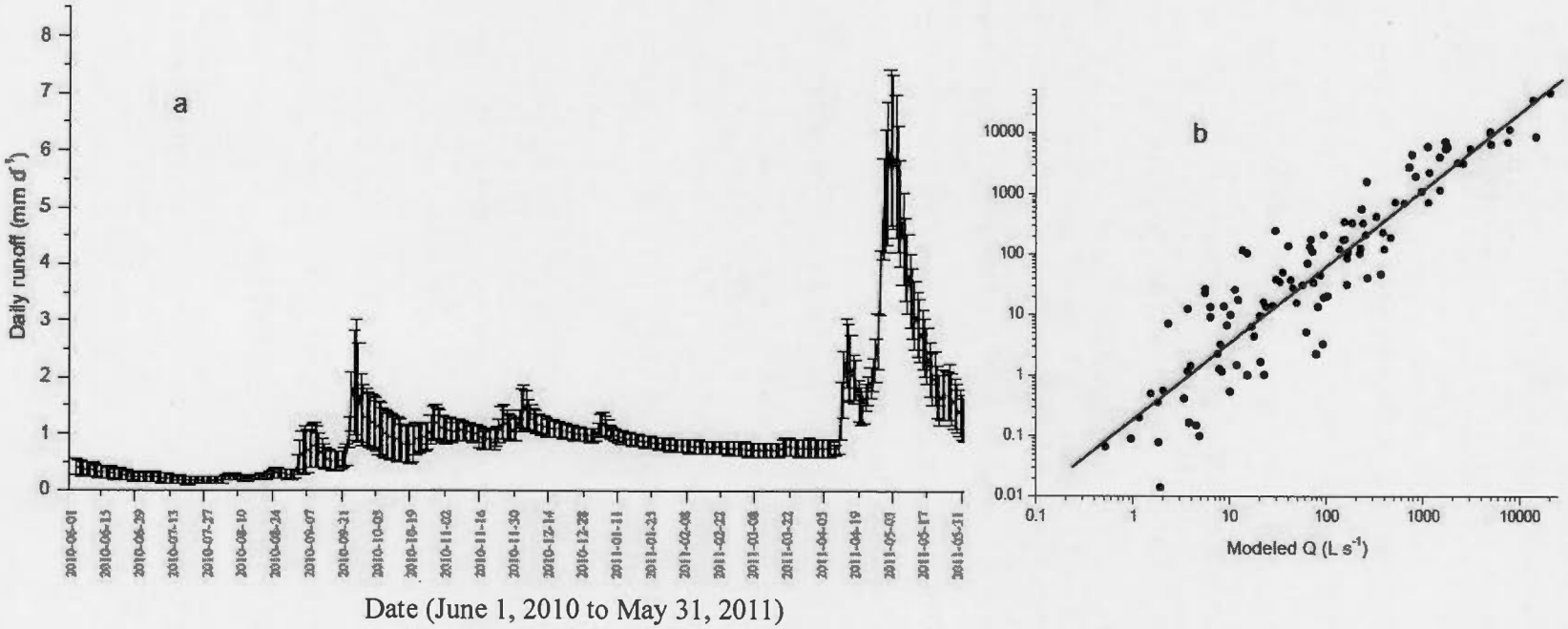

Figure 1 a. Regional daily runoff (mm d^{-1}) for the sampling year (2010), with the error bars (SD), averaged (from the daily discharges of six streams and rivers during the water year of our observation (June 1st, 2010 through May 31st, 2011). b. Relationships between estimated and measured discharge for the 44 studied rivers (R^2=0.84, n=113, p<0.0001).

2.3.4 Aquatic gas emissions

During the study period, CO_2 and CH_4 concentrations (ppm) and fluxes (mmol m^{-2} d^{-1}) across the air-water interface were measured in all the rivers (as reported in Campeau et al. (2014) and Campeau and del Giorgio (2014)). CO_2 and CH_4 concentrations were determined in situ using the headspace technique, and fluxes (mmol C m^{-2} d^{-1}) across the air-water interface were determined using the floating chamber technique, as described and reported in Campeau and del Giorgio (2014). Measurements were not made from December to March, when most of these rivers are frozen. The C fluxes of December 2010 were assumed to be 1/2 of those measured in November 2010, because most rivers and streams were ice-covered for approximately half of the month, and we assumed zero fluxes for January to March. We also used the average CO_2 and CH_4 fluxes measured in over 40 lakes in the same study region and reported by Rasilo et al. (2015) to estimate the average monthly CO_2 and CH_4 emission from lakes across the study catchments. Measurements were available for May, June, July and October 2010, so we linearly extrapolated the measured fluxes to August, September, November and December, and further used the average lake CO_2 and CH_4 evasion measured in May 2010 to estimate fluxes for April and May 2011. Average monthly lake CO_2 and CH_4 emissions within each catchment were estimated by multiplying the average measured gas fluxes by the total lake area within the catchment; likewise, average monthly total stream gas emissions were calculated as the average monthly CO_2 and CH_4 fluxes multiplied by the total stream area within catchment. Total aquatic CO_2 and CH_4 emissions are the sum of the estimated lake and stream emissions within each catchment.

2.3.5 Watershed properties

For each sampled site, the catchment area was delineated from digital maps with a resolution of 1:50,000 scale (available at Natural Resources Canada (National Topographic Data Base) and average catchment slope, lake area as well as stream length of each river order within this catchment on the maps were calculated using ArcGIS 9.3. The stream area for different stream order within the catchment was calculated separately as the product of total stream length and the average stream width of the corresponding stream order, the latter derived from the measured width for 328 across northern Quebec; total stream surface in the catchment is the sum of the total areas for each stream order existing within the catchment.

2.3.6 Statistical Analyses

In most cases, data input for modeling were log10 transformed for normality. A series of simple linear regressions were performed to explore the correlations between variables. Significance is determined at $p<0.05$ and results reported as non-significant have p values >0.05. We used JMP 9.3 (SAS institute) to do the statistical analyses.

2.4 Results

2.4.1 Riverine DOC and DIC exports

The rivers sampled in this study, as well as their respective catchments, span much of the range in physical, hydrological and chemical characteristics found in the Boreal region of Québec, summarized in Table 1. The estimated annual DOC export varied by one order of magnitude across watersheds, from 1.8 to 21.4 g C m^{-2} yr^{-1}, averaging 9.1 g C m^{-2} yr^{-1} (Table 2). The annual DIC export was systematically lower than that of DOC, averaging 2.8 g C m^{-2} y^{-1}, also ranging an order of magnitude across watersheds (from 0.5 to 7.7 g C m^{-2} yr^{-1}, Table 2).

Table 1 The physical, hydrological and chemical characteristics of the 44 catchments and the rivers sampled.

Variable	Max	Min	Mean (SD)
Catchment area (km^2)	6013.2	0.03	401.3(1261.2)
Catchment average slope (°)	5.9	0.3	2.0(1.5)
Total stream length (km)	10207.7	0.1	694.3(2210.8)
Forest coverage (%)	100	0	72.0(41.1)
Wetland coverage (%)	100	0	27.0(42.1)
Lake coverage (%)	10.0	0	1.4(2.6)
DOC concentration (mg L^{-1})	35.2	8.7	16.9(6.2)
DIC concentration (mg L^{-1})	32.6	1.9	11.3(7.3)
Total P concentration (μg L^{-1})	170.5	2.2	35.4(26.7)
Total N concentration (mg L^{-1})	1.6	0.2	0.6(0.2)
pH value	9.9	5.0	7.1(0.6)
CO_2 evasion flux (mmol m^{-2} d^{-1})	727.6	-1.6	126.3(156.8)
CH_4 evasion flux (mmol m^{-2} d^{-1})	214.5	0.03	7.5(27.2)
Average CHL *a* (μg L^{-1})	39.0	0.1	3.2(4.7)

DOC and DIC export were both significantly related, albeit in opposite directions, to average catchment slope ($logDOC_{exp} = 2.2 - 0.5$* log-slope, $R^2=0.69$, n=44, $p<0.0001$; $logDIC_{exp} = 0.61 + 0.45$*log-slope, $R^2=0.31$, n=44, $p<0.0001$) and wetlands% ($logDOC_{exp} = 2.7 + 0.21$*log-wetland%, $R^2=0.71$, n=21, $p<0.0001$; $logDIC_{exp} = -0.03 - 0.19$*log-wetland%, $R^2=0.37$, n=21, p=0.0003). It is clear that DOC and DIC export fluxes are regulated very differently in these catchments, and interestingly,

there was a strong negative relationship between both ($logDIC_{exp}$ = 2.13 – 0.67*$logDOC_{exp}$, R^2 = 0.25, n = 44, p=0.0005).

Since DOC and DIC export are both driven by the same discharge, the factors identified above appear to be mostly acting the concentrations of DOC and DIC. In particular, there was a strong negative relationship between river DOC concentration and the percentage of water in the catchment (%water), the latter mostly driven by the density of lakes within the catchment (logDOC = 1.41 – 0.16*log%water, R^2 = 0.24, n = 25, p=0.01).

Table 2 The ranges, means and medians of the fluxes of DOC, DIC, POC, CO_2, CH_4 and TC exported annually from the 44 catchments (units: g C m^{-2} yr^{-1} on catchment area basis).

C species	DOC	DIC	POC	CO_2	CH_4	TC
Max	21.4	7.7	1.1	14.7	0.4	27.3
Min	1.8	0.5	0.1	0.3	0.01	4.7
Mean (SD)	9.1 (5.3)	2.8 (1.9)	0.5 (0.3)	3.1 (3.6)	0.1 (0.1)	15.6 (5.3)
Median	6.29	2.0	0.4	1.3	0.1	14.8

2.4.2 Watershed aquatic CO_2 and CH_4 emissions

Watershed aquatic gas emissions from all aquatic surfaces within the watersheds averaged 3.1 g C m^{-2} yr^{-1} for CO_2 and 0.1 g C m^{-2} yr^{-1} for CH_4 , and ranged two orders of magnitude across watersheds for both (Table 2). CO_2 and CH_4 were significantly positively related to each other (CO_{2em} = -0.70 + 31.4*CH_{4em}, R^2=0.88, n=44, p<0.0001) and both had significant positive relationships with catchment area (CO_2: R^2=0.39, n=44, p<0.0001; CH_4: R^2=0.14, n=44, p=0.01), total stream length (CO_2: R^2=0.44, n=44, p<0.0001; CH_4: R^2=0.18, n=44, p<0.0001), stream order (CO_2: R^2=0.49, n=44, p<0.0001; CH_4: R^2=0.24, n=44, p=0.0007). In particular, CO_2 and CH_4 were both strongly positively correlated to the %water in the catchment (CO_{2em} = 1.07 + 137.2*%water, R^2=0.97, n=44, p<0.0001; CH_{4em} = 0.07 + 3.65*%water, R^2=0.77, n=44, p<0.0001).

2.4.3 Total C export from boreal catchments

Table 2 shows the average and range of total C export (TC_{exp}) from these boreal catchments, estimated as the sum of DOC, DIC and POC export and CO_2 and CH_4 fluxes. There was a strong seasonal variation in the magnitude of the average regional TC export (Figure 2a). TC_{exp} peaked in the early spring, and May and April fluxes accounting for 38% of the annual TC_{exp}, corresponding to a peak in annual discharge driven mostly by snowmelt (Figure 1a). There was a secondary peak in export in the fall, this associated to increased discharge driven by precipitation. Export was lowest in both mid-summer and mid-winter, both periods of base flow (Figure 2a). The relative contribution of C form to total C export from boreal catchments also varied greatly along the annual cycle (Figure 2b). DOC dominated TC_{exp} in the fall, winter and spring, whereas the combined CO_2 and CH_4 emissions dominated TC_{exp} during

summer (Figure 2b). The contribution of DIC to TC_{exp} was relatively constant throughout the annual cycle.

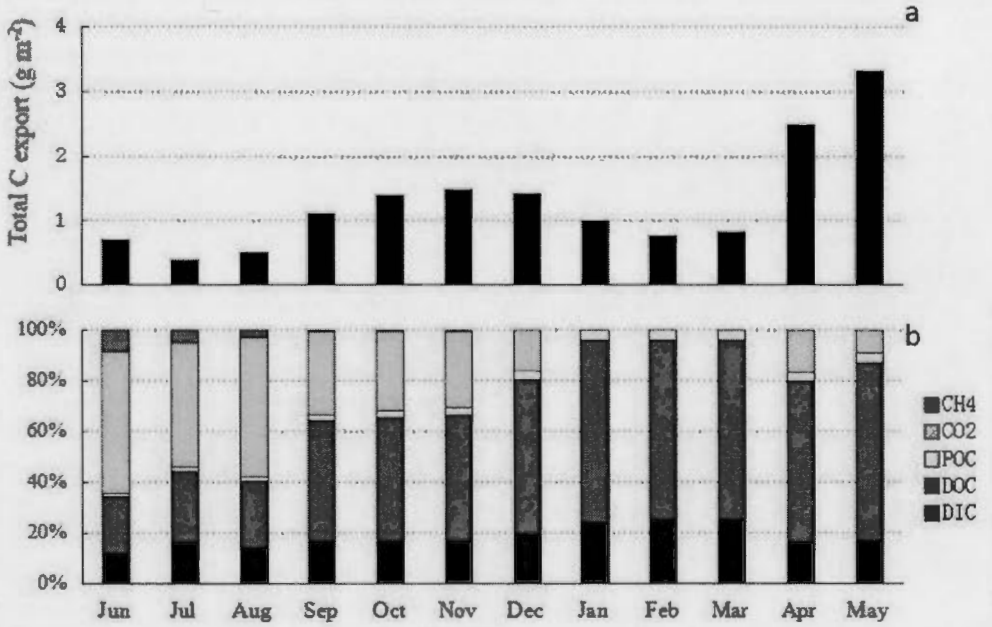

Figure 2. Total C export (a) and contribution of each C form to total C export (b) for each month in the water year. Total C export is expressed in g C per m^2 catchment area for each month, whereas the latter is expressed as percentage of each C form in total C export.

The cumulative annual TC_{exp} averaged 15.6 g C m^{-2} yr^{-1} (Table 2) across all catchments, with most values concentrating within a narrow range of 12 to 17 g C m^{-2} yr^{-1} (SE around the mean 0.8 g C m^{-2} yr^{-1}). There were significant positive relationships between TC export and catchment slope, the proportion of wetlands and of water in the catchment, and the three combined resulted in the best predictive

model of annual total C export: TC_{exp} = 15.4 – 1.35*Slope + 116.5*%water + 4.03*%wetlands (R^2=0.64, n=44, p<0.0001.

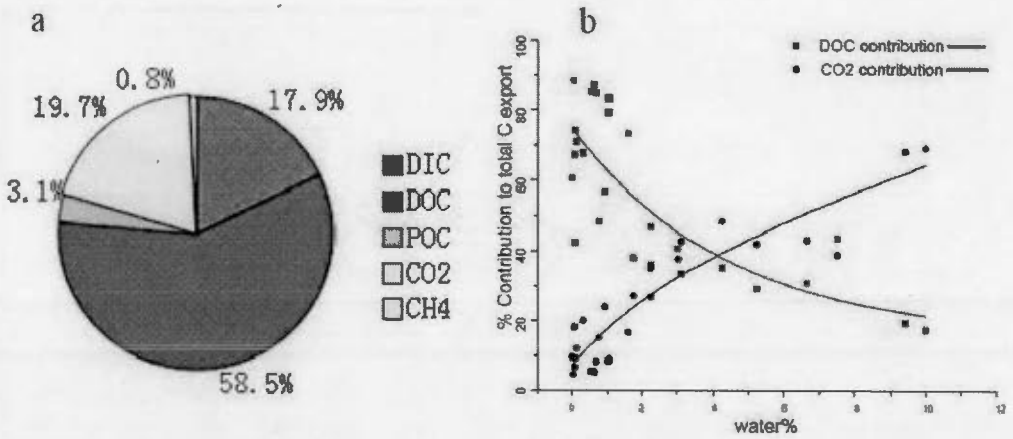

Figure 3. a. The average contribution of the various C species in the annual total C export from these boreal watersheds; **b.** The contribution of DOC export and of aquatic CO_2 emissions to total C export from these boreal catchments, as a function of the proportion of water in each catchment (% water). The latter is mostly driven by the presence of lakes. The catchments of rivers of order 1 and zero contained no lakes and were aggregated as %water = 0.

DOC dominated the average annual TC_{exp} (58.5%), whereas DIC contributed on average < 18% (Figure 3). Gaseous emissions as CO_2 and CH_4 together accounted for an average of 20.5% of the annual TC exported from these boreal catchments, overwhelmingly driven by CO_2 emissions. The estimated contribution of POC to the average annual TC_{exp} was small, in the order of around 3% (Figure 3a). The contribution of the various C species to the annual TC_{exp} varied systematically across the studied watersheds. In particular, there was strong decline in the contribution of DOC to TC_{exp} with increasing water surface in the catchment, which was mirrored

roughly by a proportion increase in the contribution of CO_2 along the same gradient (Figure 3b).

We further explored whether there were systematic differences in the magnitude and composition of TC_{exp} between the two distinct sub-regions that we covered in our study (South Abitibi and James Bay), which are characterized by very different land cover, particularly in terms of the extent of peatland cover (data summarized in Table 3). The average DOC_{exp} was 2.4-fold higher in James Bay (15 g m^{-2} yr^{-1}) compared to South Abitibi (6.3 g m^{-2} yr^{-1}), whereas the average DIC export was 2.6-fold higher in South Abitibi; the average CO_2 and CH_4 in South Abitibi were 2.5 and 3.9 times higher than those in James Bay, respectively. Interestingly, CH_4 was low in James Bay (< 0.2%), but was a significant component of TC_{exp} in South Abitibi (>1%). As a result, not only was the average magnitude of the TC_{exp} different between the two sub-regions (18.6 g m^{-2} yr^{-1} versus 14.0 g m^{-2} yr^{-1}, James Bay and South Abitibi, respectively), but also actual composition of the TC_{exp} differed substantially: Whereas in James Bay DOC overwhelmingly dominated TC_{exp} (80%), and DIC contributed very little (7%), in South Abitibi the TC_{exp} was more equally distributed between DOC (45%), DIC (25%), and C gas emissions (27% and 1%, CO_2 and CH_4, respectively) (Figure 4).

Table 3 The comparisons of physical, chemical and biological factors between James Bay and South Abitibi during the measurement period (June 1st, 2010 to May 31st, 2011). The values were annually averaged from the 14 and 30 streams and rivers we observed in James Bay and South Abitibi, respectively.

Variable	James Bay	South Abitibi
Average air temperature (°C)	0.6*	2.7*
Average catchment slope (°)	1.3	2.3
Average elevation (m)	296	304
Forest coverage (%)	20.8	97.5
Peatland coverage (%)	84.3	0.3
Lake coverage (%)	0.5	1.9
DOC concentration (mg L^{-1})	31.3	16.8
DIC concentration (mg L^{-1})	6.0	12.0
Total P concentration (μg L^{-1})	24.1	37.8
Total N concentration (mg L^{-1})	0.6	0.5
pH value	7.1	7.2
Alkalinity (μeq L^{-1})	330.2	1177.1
CO_2 evasion flux (mmol m^{-2} d^{-1})	70.6	89.6
CH_4 evasion flux (mmol m^{-2} d^{-1})	3.1	9.1
Average CHLa (μg/L)	1.2	3.4

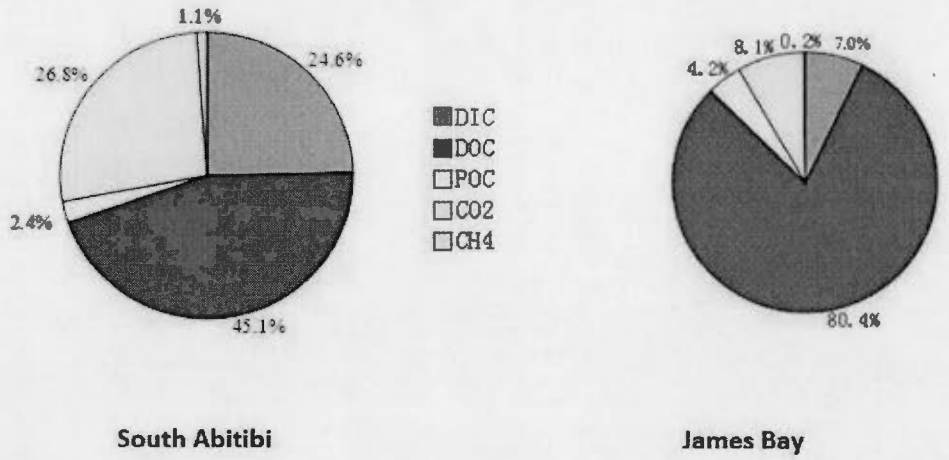

Figure 4. Comparison of the average contribution of different C forms in the annual total C export between South Abitibi and James Bay regions.

2.5 DISCUSSION

2.5.1. River-mediated DOC, DIC and CO_2 loss from landscapes

The loss of C from land to aquatic ecosystems is increasingly recognized as a significant component of the regional C budgets (Cole et al. 2007; Tranvik et al. 2009; Raymond et al., 2013). There is an extensive literature on river-mediated C loss from terrestrial systems, but relatively few studies to date have given a complete account of riverine dissolved, particulate and gaseous C exports for regional C budgets of boreal biomes yet. Our study of 44 rivers was explicitly designed to quantify C loss in different forms, i.e. DOC, DIC, CO_2 and CH_4, so as to obtain an integrated view of TC export from the landscape.

The ranges for the export of TC and of the different C species from these boreal catchments in Québec lie well within the range of values in the literature. Table 4

Table 4 Comparison of lateral and gaseous carbon exports from the watersheds in previous studies with ours. Export of each C form fro the catchments is expressed in g C m^{-2} yr^{-1}.

Watershed	Eco-region	CA*(km^2)	K_{600} m d^{-1}	DOC	DIC	POC	PIC	CO_2	CH_4	TC	Reference
Arcachon	Temperate	2657	5-10	2.1	3.4	0.4		2		7.9	Polsenaere et al., 2012
Scheldt	Temperate	18160		1.1	7.0	3.5	0.4	0.8		12.8	Abril et al., 2000
Missouri	Temperate	135716	3.9	2.5	15.0	3.1		24.9		42.5	Dubois et al., 2010
Ohio	Temperate	527000	3.9	1.3	7.6	0.9		4.2		10.4	Dubois et al., 2010
Mississippi	Temperate	2981076	3.9	0.5	3.2	0.4		4.4		8.5	Dubois et al., 2010
Krycklan	Boreal	67		3.9	0.7			5.0		9.6	Wallin et al., 2013
Yukon	Boreal	1163800	4.9-7.6	1.9	5.8	0.9	0.6	9.0	0.06	18.3	Striegl et al., 2012
Västrabäcken	Boreal	0.13		4.2	3.2			2.9			Öquist et al., 2009
NHLD	Temperate	6400		4	3			6.51			Buffam et al., 2011
Oresalven	Boreal	3025		3.6	0.9			3.8		8.6	Jonsson et L, 2007
Mer Bleue	Boreal	4.8		14.3				3.1	0.03		Billett & Moore, 2008
Auchencorth	Temperate	3.4		26.9	1.2	1.4		1.0		40.5	Billett et al., 2004
Brocky Burn	Temperate	1.3		23.7	0.5	3.3		14.1	0.1	41.2	Hope et al., 2001
Conterminous US	Temperate	208316	2.5-4.5	1.5	4.2	0.5		12.4		18.6	Stets&Striegl, 2012; Hossler&Bauer, 2013; Butman&Raymond, 2011
Zhujiang	Subtropical	650000	1.9-3.6	2.6	18.4	5.8	2.3	0.6		28.7	Yao et al., 2007; Zhang et al. 2013
Changjiang	Subtropical	1800000		0.9	11.3	0.8	0.2	8.5		21.7	Wang et al., 2007; Wang et al.,2012
Huanghe	Temperate	750000		0.1	1.5	0.3	0.1	0.1		2.1	Sun, 2007; Zhang et al., 2009
Auchencorth	Temperate	3.4		19.3	3.1	1.9		10.0	0.02	34.3	Dinsmore et al., 2013
Estrie	Temperate	2320		5.1	4.6						Chapter 1 of this thesis
Abitibi	Boreal	17140	0.67	9.1	2.8	0.5		3.1	0.1	15.6	This study

Note: CA: catchment area.

summarizes published results on lateral (dissolved) and vertical (gaseous) loss of C from different landscapes. Our range in DOC export (1.8 to 21.4 g m^{-2} yr^{-1}) agrees well with the range between 2.3 and 14.8 g m^{-2} yr^{-1} for boreal watersheds in Finland (Rantakari et al. 2010), and our average regional DOC export of 9.1 g m^{-2} yr^{-1} is close to the upper limit of the range between 3.1 and 8.4 g m^{-2} yr^{-1} for Northeast Canada given by Mulholland and Watts (1982), but somewhat higher than the mean value of 6.1 g m^{-2} yr^{-1} reported by Huotari et al. (2013) for boreal watersheds in southern Finland. On the other hand, our average DIC export of 2.8 g m^{-2} yr^{-1}, ranging from 0.5 to 7.7 g m^{-2} yr^{-1}, was significantly higher than that in Sweden (0.3-1.4 g m^{-2} yr^{-1}, averaging 0.7 g m^{-2} yr^{-1}) (Wallin et al. 2013) and Finland (TIC: 0.9-1.4 g m^{-2} yr^{-1}, averaging 1.1 g m^{-2} yr^{-1}) (Rantakari et al. 2010), but lower than that found in the Yukon River (5.8 g m^{-2} yr^{-1}) (Table 4). These regional differences in DIC export most likely reflect local geology (Tank et al. 2012), and to some extent, variations in terrestrial primary production, since a significant portion of the DIC exported actually originates from chemical weathering of rock that is mostly mediated by respiratory soil CO_2.

Our results confirm the key role of wetlands as sources of DOC to rivers (Houtari et al. 2013), but further highlight the role of surface waters, and particularly lakes, as important sinks of DOC in the landscape (Gergel et al. 1999; Xenopoulos et al. 2003), such that the balance between the relative coverage of wetlands and lakes appears to be one of the key determinants of the net DOC export from these northern watersheds. Our study provides further evidence for a differential regulation of DOC and DIC export from these boreal catchments. Whereas the export of both species is primarily driven by runoff, as has been reported before (Houtari et al. 2013), there are

differences in the drivers that determine their respective concentrations, and in particular, DOC and DIC exports significantly related to catchment slope and percent wetland, but in opposite directions. This is consistent with previous findings of our group (Li et al., 2015) and others (Houtari et al. 2013), which demonstrated a differential control DOC and DIC export in temperate and boreal watersheds. The resulting strong negative relationship between DOC and DIC export that we report here is interesting, because it is to some extent compensatory and may contributes to constraining TC export within a narrower range.

The average emissions of CO_2 and CH_4, on a catchment area basis were 3.1 and 0.1 g m^{-2} y^{-1}, respectively, and both ranged widely (see Table 2). There are only a handful of reports of total aquatic CO_2 fluxes scaled to the entire watershed, which range from a minimum of 2 g C m^{-2} y^{-1} in sub-arctic Sweden (Christensen et al. 2007) to a high 9 g C m^{-2} y^{-1} for the Yukon watershed (Striegl et al. 2012); our own average estimate of CO_2 emission (lies well within this range and close to previous boreal studies (Jonsson et al. 2007). The CH_4 value, on the other hand, is within the upper ranges of emission reported for other river systems (listed in Table 3), and over 3 times more than the CH_4 emissions from a boreal landscape located only 400 km south of our study area (Billet and Moore, 2008). One of the main reasons underlying these higher CH_4 is the widespread damming of rivers by beavers, especially in South Abibiti, which generates aquatic habitats that are particularly conducive to the production and emission of CH_4 (Ford and Naiman 1988). CO_2 significantly and positively related to CH_4 in this regions, as had been previously shown by Campeau and del Giorgio (2014), who reported a strong positive correlation between the partial pressures of CO_2 and CH_4 (pCO_2 and pCH_4) in surface water in the same study area. This positive

correlation is not surprising since CO_2 and CH_4 are both strongly driven not only by the average water surface C fluxes but mostly by the relative coverage of water in the catchment, which in turn is a function of the catchment size and slope, larger catchments having lower slopes and generally larger lakes, and thus the positive relationship of both with catchment area as well.

2.5.2 Magnitude and composition of total C export

On the whole, the magnitude of TC export from the landscape was characterized by spring>fall>winter>summer. This seasonal variation in TC tightly followed the average daily discharge curve (Figure 1), suggesting that TC export was mostly driven by the seasonal variation in discharge and therefore runoff. In particular, the TC export from April to May accounted for 38% of the annual TC export, resulting from a combination of the degassing of CO_2 accumulated under the ice, and also of high spring discharge and associated loads of DOC and DIC. Previous studies have also reported runoff as explaining 60 to over 80% of the variation in DOC and DIC export from temperate and boreal catchments (Ågren et al. 2007; Raymond and Oh 2007; Pumpanen et al. 2014; Li et al., 2015), with concentrations explaining the remainder of both the cross-system and seasonal variability in dissolved C export.

On average, the contribution of the various C species to annual TC export was DOC>CO_2>DIC>POC>CH_4, and over 90% of the TC_{exp} accounted for by the first three, in agreements with previous studies (Striegl et al. 2012; Wallin et al. 2013; Dinsmore et al. 2013, and see Table 3). On the whole, the gaseous C loss as CO_2 and CH_4, accounted for an average of 20% of the annual TC export in our study area, in agreement with the values reported for other boreal (Hope et al. 2001; Öquist et al. 2009; Koprivnjak et al. 2010; Striegl et al. 2012; Wallin et al. 2013), but significantly

higher than the 13% and 6% from temperate watersheds reported by Billett et al., (2004) and Abril et al., (2000), respectively. Our results, together with these previous studies, collectively confirm that gaseous C export is a major component of river-driven C loss from boreal landscapes.

Although DOC dominates the average regional annual TC_{exp}, its contribution within individual watersheds declines as a function of increasing water coverage in these watersheds, reaching a minimum of around 20% at the highest water densities in the landscape, whereas the contribution of CO_2 tends to peak at around 65% in these water rich watersheds. It is interesting to note that these opposing trends in DOC export and CO_2 emissions, as well as with DIC discussed above, confers a certain stability to the total C export from these boreal catchments, and helps explain why most of the estimates of TC_{exp} hover around a relatively narrow range (12 to 17 g C m^{-2} y^{-1}), in spite of the large environmental, topographic and morphometric heterogeneity that exists among these catchments. The best predictive model of TC_{exp} actually reflects the net balance in the regulation of its main components: The positive relationship with the proportion of wetlands reflects their strong positive influence on DOC export, whereas the positive effect of the proportion of water suggests that the enhancement of C gas emissions with increasing water surface is not offset by the decline in DOC that occurs along the same gradient; the positive effect of catchment area on TC_{exp} further reflects increases in runoff as a function of catchment size, as well as in total gas emissions and DIC export. We should note that in this study POC was not measured and was rather assumed to be a fixed proportion of DOC, so no actual conclusions can be drawn for this particular C species, but existing evidence suggests that its contribution to TC_{exp} in these mostly

non-agricultural watersheds should be minor (Ivarsson and Jansson 1994; Hope et al. 1994).

The interplay between the average contribution of DOC and CO_2 along a gradient of water density among catchments occurs to some extent within a given catchment in time. We have shown that there is a clear temporal succession in the relative contribution of the main C species along an annual cycle, with a peak contribution of DOC during periods of high discharge, and dominance of CO_2 during summer low flow periods. The mechanisms underlying this replacement are probably different: Whereas the replacement of DOC for CO_2 across catchments likely reflects the increased photochemical and biological degradation of terrestrially derived DOC that occurs with increasing water coverage and thus water residence time, the temporal succession reflects seasonal shifts in discharge and aquatic metabolism (Vachon and del Giorgio 2014). The increase in the relative contribution of CO_2 during these low flow periods results from a combination of declines in the loading of DOC, and increases in the actual aquatic CO_2 fluxes, likely driven by temperature- and light-enhanced DOC degradation within lakes. The seasonal pattern in both CO_2 and CH_4, with marked peaks in mid-summer, also likely reflects a temperature effect, consistent with Billett et al. (2004), Koprivnjak et al. (2010) and Kosten et al. (2010) who reported a strong positive correlation between temperature and CO_2 evasion.

2.5.3 Cross-regional differences in the magnitude and composition of C export

It is interesting to note that there are major differences in both the magnitude and the actual composition of TC_{exp} between the two sub-regions, James Bay and South Abitibi, that coexist with our general study area but which are very distinct in terms of land cover and to some extent climate (see table 4 for a summary). The total CO_2

and CH_4 emissions in James Bay were 2.5-fold lower those in South Abitibi, to some degree, reflecting the effects of regional temperature and water coverage, whereas DIC export was substantially higher on average in South Abitibi, possibly related to differences in both underlying geology as well as in temperature-driven soil respiration and the resulting chemical rock weathering. The largest difference that we found between the regions, however, was in the DOC export, which was 2.4-fold higher in James Bay, driven by a 2-fold higher average river DOC concentration there (Table 3). These elevated DOC concentrations in James Bay are likely related to the much higher peatland coverage (12.6-100% vs. 0-4% of the total area) and smaller catchment slope (1.3 vs 2.3 on average), and reinforce the importance of these factors in determining DOC concentration and export from land (Eckhardt and Moore, 1990; Dillon and Molot, 1997).

2.5.4 Implications to terrestrial C budgets

The lateral C export from land to water that we report here must be placed in the context of the whole C budget of this boreal landscape. Much of the recent empirical and modeling work has focused on better constraining the net CO_2 exchange between various landscapes and the atmosphere (i.e., Net Ecosystem Production, NEP), in order to determine the role of these ecosystems as sources or sinks of atmospheric C. NEP varies greatly with geographic location and climate, but also within a given site as a function of stand age, fire history and clear cutting (Bergeron et al. 2008; Goulden et al. 2011), and also as a function of inter-annual differences in precipitation and temperature (Litvak et al. 2003). Moreover, there is evidence of long term shifts in the net C balance of landscapes within the boreal biome. For example, Dunn et al. (2007) reported a decade-long shift in net C uptake in a boreal

landscape dominated by black spruce, from being small source of C (-41 g C m^{-2} y^{-1}) to more recently become a small sink (+21 g C m^{-2} y^{-1}). Not surprisingly, there is a very large range in net CO_2 exchange reported for boreal forests, from −100 to 250 g C m^{-2} yr^{-1} (Ryan et al. 1997; Hyvönen et al. 2007).

In this regard, very few current models of terrestrial primary production and C storage include lateral C losses (i.e. Hayes et al. 2012; Regnier et al. 2013; Wu et al. 2013), and even fewer incorporate aqueous C emissions, although there is ample evidence that these fluxes are regionally significant, particularly in boreal landscapes (Battin et al. 2009; Wallin et al. 2013). A key issue is then to what extent current approaches to estimating NEP include this TC_{exp}, and if they do, what components of TC_{exp} are included (Fiedler et al. 2006; Hyvönen et al. 2007). Estimates based on eddy covariance towers may incorporate some of the aquatic C emissions, depending on the location of the tower, but certainly do not include all the C components lost to the aquatic network (Kljun et al. 2006). For example, recent studies have reported that unexpectedly high losses of soil C had to be invoked in order to mass balance the apparent net CO_2 uptake with the observed long-term ecosystem C accumulation, and these were attributed to increased respiration (Lindroth et al. 2008), but it is likely that at least a portion of this soil C loss resulted from the lateral export soil DOC and DIC to the aquatic network. The few previous studies that have explicitly attempted to integrate the main components of the lateral C export to water all converge to point out that TC_{exp} is a significant component of regional C fluxes and consistently within the order of magnitude as the NEP in for their respective regions (5% to over 80% of the local NEP, Buffam et al. 2011; Fieldler et al. 2006; Christensen et al. 2007; Jonsson et al. 2007; Striegl et al. 2012).

In this regard, although there is an extensive literature on boreal terrestrial primary production net C exchange, there are few direct estimates of NEP for this region in particular. Girardin et al. (2011) report an average NEP of around 150 g C m^{-2} y^{-1} for the southern portion of the Abitibi region of boreal Québec, whereas Bergeron et al. (2007) report a much lower NEP, in the order of 4 g C m^{-2} y^{-1} in the nearby region of Chibaugamau. Some of this difference may be methodological, because the former was based on estimates of C stocks and tree productivity, whereas the latter is based on eddie covariance data. This large range in reported NEP for this region also likely reflects the large degree of heterogeneity that exists in this boreal landscape, driven by local climate, fire history and more recently, forestry. Regardless, the estimated TC_{exp} in the Abitibi region that we report here is likely to play a key role in determining what portions of this vast boreal landscape act as either a source or a sink of atmospheric C. This is particularly true for the James Bay region, which is drier and colder than the adjacent South Abitibi and thus likely approaches the lower reported range of NEP, and which is nevertheless characterized by a higher estimated TC_{exp} (18.6 g m^{-2} yr^{-1} vs 14 g m^{-2} yr^{-1}, James Bay and South Abitibi, respectively). This implies that the relative contribution of TC_{exp} to the whole landscape C budget is likely to be even larger in the James Bay region than it is for Abitibi in general. Interestingly, these TC_{exp} are in the same range of estimated fire-driven CO_2 fluxes to the atmosphere (Van Bellen et al. 2010), yet whereas the latter are incorporated into most terrestrial C models for these regions, the former are not. More generally, the large degree of uncertainty that still characterizes most estimates of net terrestrial C sink or sources may be at least in part related to the non-inclusion of this lateral loss to the aquatic components of the regional C budget.

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CHAPTER III

A GLOBAL ANALYSIS OF RIVERINE CARBON EXPORT TO THE OCEANS

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N.B. References cited in this chapter are presented at the end of the thesis

3.1 Abstract

Riverine carbon (C) export to the oceans is a key component in the global C cycle, yet it is still poorly constrained. This is largely the result of the limited data base used to derive a global flux and because most studies assessed the inorganic or organic fraction separately, thus yielding a fragmentary perspective of C exported to oceans. Here we revisit the global riverine C export, based on the meta-analysis of published data covering 566 rivers draining 74% of the global exorheic area. This analysis yields a new global annual riverine C export of 0.68±0.05 Pg yr^{-1}, substantially lower than the widely-cited 0.9 Pg yr^{-1}. Our results show that, at a global scale, the organic and inorganic components of C export are driven by different combinations of natural and human-derived features of the landscape. Beyond the expected hydrologic control on material transport, DOC export was mainly controlled by natural characteristics such as the presence of wetlands as well as the organic carbon content of the surface soil layer. On the other hand, the natural drivers of DIC export were the extents of carbonate rocks and water surface in the watersheds. However, all forms of carbon

were also shown to be dependent on the extent of croplands within the catchments, and strongly so for the inorganic fraction. A retrospective analysis suggests that 40% of the current C delivery to the oceans is associated with agriculture. Our multiple regression models demonstrate that cropland expansion may be a primary driver of future riverine C export not only in magnitude but also in its composition. This study further highlights the differential regulation of global inorganic and organic C exports and can serve as a strong basis for identifying the implications of future climate and human-induced environmental changes on this important component of the global carbon cycle.

3.2 Introduction

Riverine transport of C to the oceans is the ultimate leachate of terrestrial carbon. Following the pioneering assessment of Meybeck and coworkers, it is a significant component of the global C cycling and quantifying it is essential to a better understanding of the Earth's biogeochemical and climatic systems, particularly in the context of global change (Lal, 2003; Aufdenkampe et al., 2011; Cole et al., 2007; Battin et al. 2009). How much and in what form continental C is lost to oceans have thus been of major biogeochemical interests for several decades. Regionally, the main drivers of carbon export are relatively clear. The combined effects of topography, hydrology, climate and land use/cover change on riverine C export from landscapes are well known(D'Arcy and Carignan, 1997; Hazlett et al., 2002; DeCatanzaro and Chow-Fraser, 2011; Freemanet al., 2004) and the importance of the inland aquatic processing of this terrestrially-derived carbon is an active research area (Cole et al. 2007; Tranvik et al. 2009; Raymond et al., 2013). Although global estimates of riverine C export to the oceans have been periodically re-assessed (Richey et al., 1980;

Meybeck, 1982; Schlünz & Schneider, 2000; Dai et al; 2012; Seitzinger et al., 2010), their accounting is surprisingly poorly constrained (Schlünz & Schneider, 2000) because of either differences in approaches or of the limited riverine C data compilations. Nevertheless, published estimates tend to converge around 0.9 Pg yr^{-1}, a value that has been widely cited as the global total riverine C flux (Cole et al. 2007; Battin et al. 2009; Tranvik et al. 2009; Bauer et al., 2013).

Most previous estimates considered only some of the four C components (dissolved and particulate, organic and inorganic carbon species; DOC, POC, DIC and PIC, respectively), thus yielding a fragmented perspective of riverine C exported to the oceans and contributing to the uncertainty of the estimate of global C exported in different forms from the terrestrial biosphere. Moreover, these global estimates are generally derived from a few to a few dozen large rivers and extrapolated to the rest of the globe, thereby assuming an untested representativeness. Considering that there are about 740 rivers draining into the oceans that have individual catchments >10,000 km^2, arriving at a more accurate estimate of the global riverine C export to the oceans will necessarily require a better or complete geographic coverage but will also benefit from the identification of the main drivers determining the export of the various carbon forms at the planetary scale.

In this synthesis, we compiled literature C data of field measurements from 566 rivers worldwide, draining a total of 74% of the global exorheic area (Antarctica is excluded from this study) and combined it with land cover and other catchment information to identify the large scale determinants of C export. The resulting models were then applied to the remaining (unsampled) rivers of the world to better constrain the global riverine export of different C species to the coastal oceans. In addition, we explored

the relative roles of natural and human-altered landscape features on the delivery of various forms of carbon and their potential implications in the context of global environmental change.

3.3 Results and discussions

3.3.1 Drivers of riverine C export

A review of the literature reveals that riverine C export differs widely among individual rivers due to the large variation in catchment topography, vegetation, geology, climate and hydrology (Hope et al. 1994; Pacific, 2009; Tank et al., 2012). To assess their relative importance at the global scale, we developed multivariate models to test specifically the importance of catchment characteristics, such as land cover (amalgamated into broad categories: forests, croplands, wetlands and water, see Supplemental Information S2), soil organic carbon, mean annual runoff, mean annual temperature, carbonate rock outcrops, and catchment slope and area. In addition, we examined the potential influence of some specific human alterations to the landscapes, such as the increased water residence time and river segmentation induced by the creation of large dams (SI3). Average population density was also a candidate variable and was assumed to be a good proxy of human disturbance. The models were developed using the elastic net variable selection procedure combined with BIC validation, as implemented in JMP Pro version 12. Variables retained in the final models each bring independent information useful to the description and prediction of carbon export.

Without surprise, we found like many regional studies (Hope et al. 1994; Pacific, 2009; Tank et al., 2012) that all forms of carbon export were ultimately constrained

by the amount of water flushing through the catchments (as runoff, mm yr^{-1}). However, beyond this simple hydrologic control, each form of carbon exported was determined by different sets of landscape features. At this global scale, the non-hydrological variations in DOC export was best explained by edaphic characteristics of their catchments, such as the soil organic carbon (SOC 0-30cm, kg C m^{-2}) and the extent of wetlands in the catchment. We were also able to detect the significant influence of two important human alterations to the landscape on DOC export: the extent of croplands and the presence of large reservoirs within the catchment (expressed as the additional residence time of water, AWRT, within the catchment; DOC vs AWRT: R^2=0.11, n=442, p<0.0001). Lastly, we found that large catchments tended to export less somewhat carbon per unit area, suggesting that a greater mineralization and loss of DOC during the transit through the hydrological network. At the global scale, the relative importance of the various influences ranked as follows: Hydrology > Soil organic carbon > %Wetlands > %Croplands ≈ Catchment size > AWRT.

Variations in DIC export were also best explained by a combination of natural and human-altered features of the landscape. Like DOC, DIC export is tightly controlled by the regional hydrology (runoff). However, and not surprisingly, it is also strongly and positively modulated by the presence of carbonate rocks within its catchment. Moreover, it is negatively modulated by the fraction of the landscape covered by water. The mechanisms behind both of these natural drivers are easily understood. In the former, the chemical weathering of carbonate rocks by soil respiratory CO_2 is a primary source of alkalinity (i.e. HCO_3^- and CO_3^{2-}), which constitutes the bulk of DIC in most cases. Rivers draining catchments with a large proportion underlain by

carbonate rocks naturally yield more DIC. Similarly, the negative influence of water coverage likely reflects the converse mechanism: catchments with a lot of water surface simple have a smaller surface over which this chemical weathering of soil minerals can occur. In this respect, inland waters largely act as passive transport pipes for these conservative ions (HCO_3^- and CO_3^{2-}). Beyond these natural controls however, our analysis revealed the important influence of the extent of agricultural activities on DIC export. Collectively, they explain about 57% of the global variation in DIC export, including a small but significant positive effect of catchment size. Their relative importance follows Hydrology > %Croplands ≈ %Carbonates > %Water > Catchment size.

Always in much smaller amounts than its dissolved counterpart, the particulate fraction of organic carbon (POC) was also a significant multivariate function (R^2=0.47) combining hydrology and both natural (%Water) and human-altered (%Croplands) features of the catchment landscapes. The inverse relationship between POC export and water coverage can probably be ascribed to POC deposition and burial in the sediments, and/or the greater POC potential degradation because of longer residence time in lakes or reservoirs. Conversely, the positive association between %Cropland and POC export can result from the greater erosional soil losses of croplands relative to forests. Table 1 summarizes the global models for the different forms of carbon. For PIC export, the limited number of observations (n=36 rivers) precluded the development of a specific multivariate model. Instead, we used the median ratio of 10% between PIC and DIC export observed in the 36 rivers and applied it to all the other catchments. This approach, while necessarily coarser, best captured the observed variability in PIC export.

While the importance of wetlands and soil organic carbon content to DOC yield is not new to the literature (Dillon and Molot 1997, Aitkenhead and McDowell 2000), our global model can be solved (fig. SI4.1) to assess how DOC export varies in different regions of the world depending on local hydrologic regimes (runoff, mm yr^{-1}) and soil organic carbon content (SOC, kg C m^{-2}) when all other variables remaining equal at their mean values. For SOC> 10 kg m^{-2}, the relationships are nearly linear, suggesting DOC export can be viewed as a first-order reaction with the soil organic C reservoir eluted with different efficiencies depending on the annual runoff. As a general rule, DOC export corresponds to a rate varying narrowly between 0.02 and 0.07% of the SOC per year per mm of runoff. Solving the model further for units of pure cropland, this removal rate increases only slightly to 0.03-0.1% yr^{-1} per unit runoff (mm) while a pure wetland unit would remove about 0.3-0.5% yr^{-1} per unit runoff (mm), indicating a much greater removal rate of wetland organic carbon.

To our knowledge, our study is the first to detect a significant influence of large reservoirs (>0.1 Mm^3 capacity) on DOC yield. Although largely exploratory in scope, our analysis suggests that the longer water residence time induced by the creation of large reservoirs for a variety of purposes (flood control, irrigation, hydroelectricity) may favor a more complete degradation of the DOC, biologically or photochemically, into DIC (Lapierre et al., 2013; Spencer et al., 2009) during its transit.

Table 1 Multiple linear regression models predicting DOC, DIC and POC export in g m^{-2} yr^{-1}. Estimates of coefficients and corresponding *p* values are given for all variables offered during the elastic net selection process. Variables were included in the model if $p<0.001$ and the corresponding R^2 values are shown.

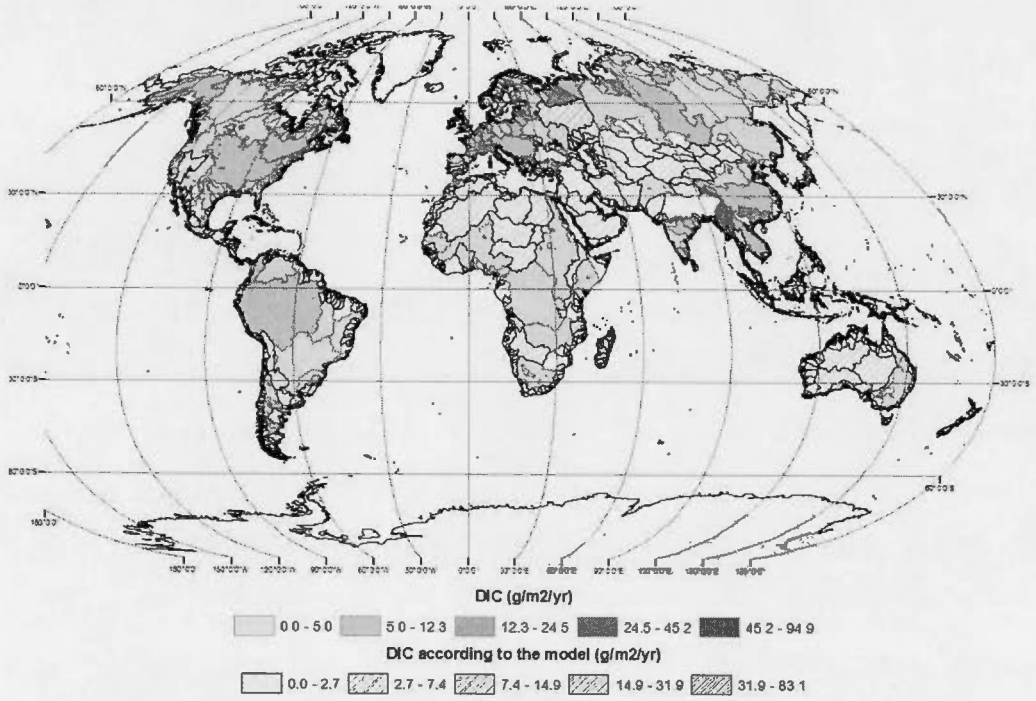
Parameter	DOC export		DIC export		POC export	
	Estimate	*p*	Estimate	*p*	Estimate	*p*
Annual runoff (mm)	0.744	<0.0001	0.781	<0.0001	0.899	<0.0001
Catchment area (km^2)	-0.070	<0.0001	0.102	0.0003		
Soil organic carbon (kg m^{-2})	0.326	<0.0001				
%croplands	0.022	<0.0001	0.055	<0.0001	0.049	<0.0001
%wetlands	0.202	<0.0001				
%water body			-0.114	<0.0001	-0.155	<0.0001
%carbonates			0.058	<0.0001		
Intercept	-1.863		-2.117		-2.652	
R^2	0.70		0.57		0.47	
n	427		404		339	

Notes: In the models, C export, annual runoff, catchment area and soil organic carbon are log 10 transformed, %croplands, %water surface and %carbonates are square root transformed, and %wetlands is 0.25-power transformed.

3.3.2 A new estimate of global riverine C export to the oceans

The development of the statistically robust models at this global scale has not only further clarified the relative importance of different controls on riverine C export to the oceans, they also allow us to estimate carbon export to the oceans from the rest (26%) of the global exoreic area where no measurements of carbon export have been found in our data compilation. These represent 5098 watersheds of more than 3 km^2. Combining the measured values of the 566 rivers with the modeled estimates for the unmeasured catchments yielded a new estimate of the global riverine C export to the oceans. Figure 1 shows the global distribution of measured (solid colors) and modeled (hatched) DIC and DOC exports (Figure 1a and 1b, respectively).

a Global Distribution of DIC export



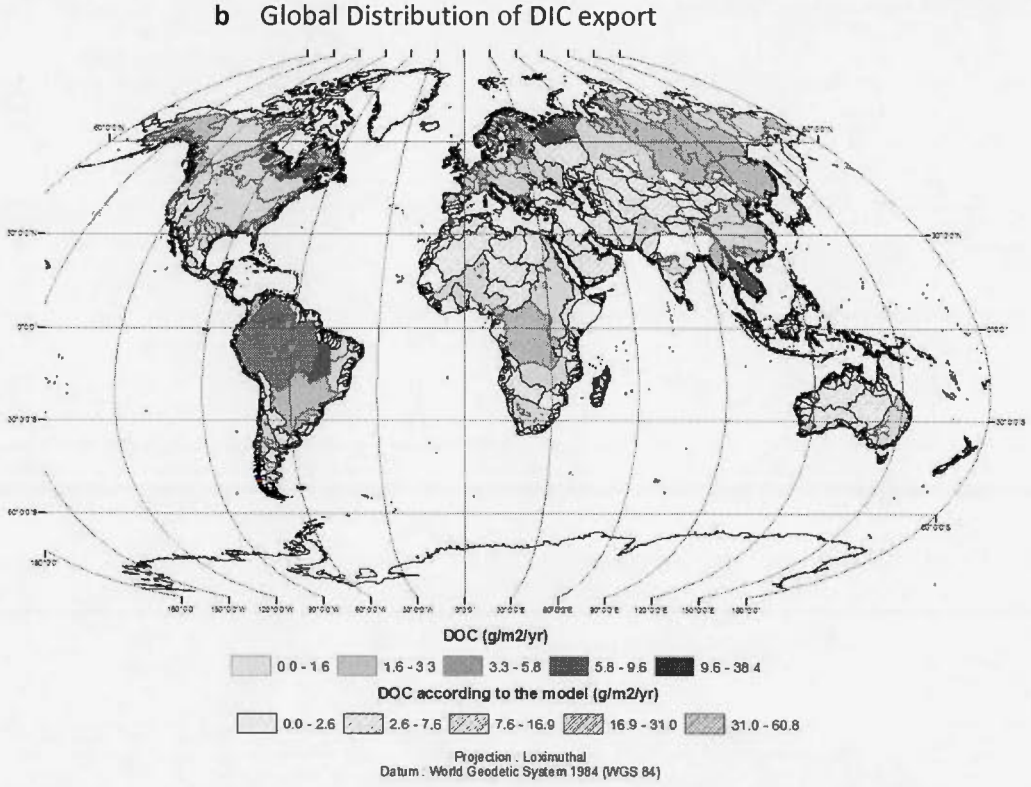


Figure 1 Maps of Global Distributions of DIC and DOC Exports

Our assessment yielded a total global C export of 0.68±0.05 Pg yr^{-1}, of which DOC, POC, DIC and PIC exports represent 0.18±0.01, 0.07±0.01, 0.39±0.02 and 0.04±0.01 Pg yr^{-1}, respectively. Our new estimate thus constitutes a significant downward revision of the widely used global C export value of 0.9 Pg yr^{-1}. For comparison, Table 2 compiles our new estimates with those previously published and it highlights that the largest differences are in the POC and PIC export. Our POC export estimate of 0.07 Pg yr^{-1} is much lower than the value of around 0.18 Pg yr^{-1} reported in previous studies (Meybeck, 1982; Galy et al., 2015; Ludwid et al., 1996) although consistent with the value of Garrel et al. (1973). We suggest that the global POC

export may have been overestimated in the past primarily because of limited data. The largest data compilation of global POC export previously published was based on only 70 rivers, in comparison to the 359 watersheds used in this study, covering a total of 64% of the global exoreic area. Even our own estimate may be somewhat inflated. In our data set, 63 POC export values from catchments located in Sweden and Canada were based on the assumption that POC corresponded to 5% of TOC though the studies indicated that POC is generally less than 5% of TOC in concentration (Clair et al., 1994; Clair et al., 2013; Laudon et al., 2004). Furthermore, it is often reported that small mountainous rivers (basin area: <10,000 km^2 and headwater elevation: 1000 to 3000 m) have an extremely high POC flux (Milliman & Syvitski, 1992; Lyons et al., 2002; Komada et al., 2004), especially in the southwest Pacific. Our study included 234 small rivers, of which 54 rivers are in the southwest Pacific, only showed a very weak relationship between POC export and elevation (R^2=0.03, n=254, p=0.007), and this variable was not retained in the POC model using the elastic net variable selection procedure.

Table 2 The comparisons of our estimates of global riverine carbon export to the oceans with those in previous studies

	DOC	DIC	POC	PIC	TOC	TIC	TC	Rivers used
This study	**0.18**	**0.39**	**0.07**	**0.04**	**0.25**	**0.43**	**0.68**	**566**
Meybeck, 1982	0.22	0.38	0.18	0.17	0.4	0.55	0.95	27
Meybeck, 1993	0.20	0.38	0.18	0.17	0.38	0.55	0.93	60
Mackenzie et al., 1996					0.61	0.72	1.33	
Aitkenhead & McDowell, 2000	0.36							164
Cauwet, 2002	0.25							
Dai et al., 2012	0.17							118
Degens et al., 1991					0.33			
Duce and Duursma, 1977					0.13			
Galy et al., 2015			0.20					70
Garrel et al., 1973	0.13		0.07		0.20			
Handa, 1977					0.30			
Harrison et al., 2005	0.17							68
Kempe, 1979		0.44			0.19			
Kempe, 1985					0.28			
Ludwig et al., 1996a	0.21	0.32	0.19		0.40			
Ludwig et al., 1996b	0.21		0.17		0.38			48
Mantoura & Woodward, 1983	0.78							1
Michaelis et al., 1986					0.53			
Reiners, 1973					0.2~1			
Richey et al., 1980					1.00			1
Schlesinger & Melack, 1981					0.39			12
Schlunz & Schneider, 2000					0.43			18
Smith & Hollibaugh, 1993	0.20							
Spitzy & Ittekkot, 1991					0.50			
Stewart et al., 1978					0.52			
Williams,1971					0.03			

For PIC export, significant uncertainty remains given the limited data we were able to compile (only 36 rivers) and their geographic coverage (about 16% of the global exoreic area). However, we argue that our estimate of the global PIC export of 0.04 Pg yr^{-1} is nevertheless reasonably constrained from the ratio DIC:TIC observed 111 rivers, (median: 0.95; average: 0.96) suggesting that, on average, PIC represent only about 5% of the TIC export, lower than the fraction we used to estimate it. Our resulting estimate can therefore be considered an upper limit but is much lower than the previous reported value of 0.17 Pg yr^{-1} (Meybeck, 1982), which was itself derived by assuming that PIC is a constant 1% fraction of total suspended matter (Meybeck, 1982; Huang et al., 2012).

3.3.3 Past and future effects of anthropogenic disturbances on global river C export

Human activity is widely regarded as an important driver of global environmental change, especially in the past five decades, during which the rapid development of world's economies is characterized by the expansions of agriculture, industry and urbanization. Our models all include the fraction of the catchment used as croplands as a major driver of C export. They can therefore be used to estimate how much of the current global export may be attributed to agriculture. Recalculating the export of all 5664 catchments while imposing 0% cropland results in a global estimate of 0.40 Pg yr^{-1}, suggesting that the current extent of agriculture worldwide accounts for 0.28 Pg yr^{-1} (about 40%) of the present global carbon export to the oceans. According to our models, the bulk (nearly two thirds) of this carbon associated with agriculture is inorganic, consistent with the results from the Mississippi basin where the extent of croplands within various sub-basins was directly related to alkalinity export (Raymond and Cole 2003). Projections from the FAO of agricultural requirements to

feed the world's growing population (Alexandratos and Bruinsma 2012) suggest that croplands will expand at a rate of about 0.1% per year over the 2050 horizon. This value is the net result of forecasted reduction in croplands in developed countries (at a rate of -0.14% per year) but a much faster increase in the developing world (+0.24% per year), particularly in Latin America (+0.49% per year). Depending on the carbon export profile of agricultural land abandoned because of severe land degradation and also on the geographical location of this future expansion, our models suggest that total carbon export could increase by up to 15 % by 2050. Much greater changes can be expected at local scales. Taking the Changjiang catchment as an 'example, if %cropland increases from the current 34% to 80%, and assuming other variables remain constant, the total C exported to the coastal ocean by this river will increase by 45%. As a general rule, it is the DIC and POC exports that are the most sensitive carbon forms to a conversion to cropland. This therefore implies that global cropland expansion will modify riverine C export not only in its magnitude but also in its composition. The potential consequences of such compositional changes on the oceanic carbon processing are currently unknown but may alter significantly the functioning of the coastal ecosystems receiving these carbon loads.

Similarly we can consider the potential effects of changing climatic regimes on carbon export. Using the scenario proposed by Cao et al. (2010) that a doubling in atmospheric CO_2 would results in a 15% increase in runoff, our model would suggest a commensurate increase of about 12% in total carbon export. While this conclusion depends strongly on the geographic distribution of the predicted increases in runoff, such predictions could nevertheless be integrated to our modeling approach to yield better predictions of climate induced effects on C export. Regardless of the exact

magnitude of changes, our study highlighted that anthropogenic disturbances, past and future, may have become the most important factors modifying the magnitude and composition of riverine C export from terrestrial to aquatic ecosystems, particularly in the context of global environmental change.

3.4 METHODS

In this study, all the data on C concentrations and exports to the oceans are collected from journal papers, technical reports and books published after 2000. The complete data compilation is provided in SI-Table 5.1. All the riverine C concentrations and exports were field observed for at least 1 year with a frequency of at least 3-4 times. Some big rivers were measured several times for different studies. In this case, we use the average of the values for that river. Riverine C export, when not provided directly, was calculated as *C export (g m^{-2} yr^{-1}) = C concentration (mg L^{-1}) X annual discharge (m^3)/catchment area (m^2)*. All the data on river discharge and catchment area are based on Meybeck and Ragu (1996) or the specific references, while river mouth coordinates are corrected by Google.Maps. The catchment delineation for each river basin was obtained from the HydroBasins product (http://www.hydrosheds.org/page/hydrobasins) matching the river mouth locations. The basin polygons were then used to extract the catchment characteristics using the global raster files for annual runoff (mm yr^{-1}), catchment slope and area.

The same process was then applied to all other exorheic catchments draining into the oceans thereby allowing the application of the multivariate models to all catchments that had not been sampled in our database. All statistical analyses were performed in JMP Pro 12. Variable selection for the multivariate regression models was carried out using the elastic net algorithm coupled with the Bayesian Information Criterion (BIC)

validation procedure, as implemented in JMP Pro12. Although this procedure does not necessarily rely on probability levels for variable retention, all the variables retained in the models were statistically significant ($p<0.001$ in all cases).

CHAPTER IV

CONCLUSIONS

4.1 Main contributions:

The common theme of this thesis is to explore the natural and anthropogenic drivers of carbon export from watersheds to aquatic ecosystems, as well as the relative importance of individual drivers in controlling the magnitude and composition of the total carbon exported in different forms to the receiving waters, through systematically analyzing the carbon database of 127 rivers and streams in Quebec that had been sampled for 1-3 years by the Aquatic group of UQAM, and then shifts the study from a catchment and regional scale to the global scale for a further exploration of them based on the global carbon dataset that were pooled and integrated from the previously-scattered knowledge and data in the literature regarding riverine carbon export to the oceans. On the basis of the combination of the large amounts of regional and global C data, this thesis has (re)assessed and predicted the magnitude, composition and trend of the total carbon exported from watersheds to the receiving waters at different spatial and temporal scales, and developed a better understanding of the role and importance of riverine carbon export in regional and global carbon cycles, quantitatively and qualitatively.

Specifically, the following key points emerge from the different chapters:

4.1.1 The study on the relative influence of topography and land cover on inorganic and organic carbon export from temperate catchments has simultaneously explored DOC and DIC export to river systems, based on a large amount of regional observations that maximize the spatial coverage and environmental gradients and that captures some of the seasonal variability in river discharge and C concentration. This study has clarified the role and importance of different individual drivers of DOC and DIC exports from the watersheds, in particular, that topography is more important than land cover in explaining the variance in DIC export, whereas land cover is much more important than topography in terms of DOC export. This further highlights human activities that lead to land use/cover change, such as urbanization, deforestation and wetland clearance, can potentially modify the magnitude and composition of the total C export from watersheds. The exploration of the inter-annual variation of DIC and DOC export from these temperate catchments demonstrates that the fluctuations in precipitation and temperature due to climate change or global warming would to some extent modify TC export and DIC/DOC ratio, because of the different responses of DOC and DIC exports to precipitation and

temperature, which could provide some bases for the prediction of C export and water quality changes triggered by regional or global climate shifts.

4.1.2 As a follow up of the patterns observed in the first chapter and in order to further understand environmental drivers of carbon export to river systems in the boreal biome, the second chapter focused on the export of dissolved (DOC and DIC), and gaseous (CO_2 and CH_4), so as to quantify the spatial and temporal variations in the magnitude and composition of the total carbon exported from a wide range of boreal watersheds.Total export peaked in spring and varied widely in its magnitude and composition seasonally, but was dominated by DOC on an annual basis. The integrated aquatic CO_2 emissions were also a major contributor to the total C export from these watersheds, and replaced DOC as the dominant C species in watersheds with high water densities.

4.1.3 On the basis of Chapters 1 and 2 that addressed the natural and anthropogenic drivers of carbon export from either temperate and boreal watersheds to river systems and the composition and magnitude of total carbon exported in different forms at a regional scale, the third chapter shifts from a catchment and regional scale to the globe to explore the natural and anthropogenic drivers of global riverine carbon export to the oceans, and to reassess the global riverine carbon export rate based on a

synthesis and meta-analysis of the most extensive river carbon dataset assembled to date. We produce a new annual global riverine carbon export rate of 0.68 Pg C yr^{-1}, 24% less than the widely-accepted value of 0.9 Pg C yr^{-1} (e.g. Battin et al., 2009; Cole et al., 2007; Tranvik et al., 2009). Our revised estimates of global DOC and DIC export, 0.18 and 0.39 Pg C yr^{-1}, respectively, are similar to the widely-used values of around 0.2 (e.g. Meybeck, 1982&1993; Ludwig et al, 1996; Harrison et al., 2005; Dai et al., 2012) and 0.38 (Meybeck, 1982&1993) Pg C yr^{-1}, respectively. However, we narrowed the uncertainties of the previous estimations of POC and PIC exports and obtained the annual global riverine POC and PIC exports of 0.07 and 0.04 Pg C yr^{-1}, respectively, using the most extensive POC data coverage to date. This global study also has further clarified the relative importance of different drivers of riverine carbon export from terrestrial ecosystems at a global scale. Our multiple regression analyses have further shown that human activities, especially cropland expansion, may become a main regulator of the magnitude and composition of total riverine carbon export to the oceans in the future. Our models predict that a 15% increase in runoff, predicted under a doubling of atmospheric CO_2 (Cao et al., 2010) could lead to an increase of 12% in total carbon export to the oceans, whereas increases in the cropland area will result in proportionately larger shifts in the magnitude and composition of total C

export. For example, an increase in cropland coverage in the Changjiang catchment from the current 34% to 80% of the total surface would result in an increase in the export of DOC, DIC and POC by 17%, 48% and 42%, respectively, with a resulting increase in total C export from this catchment of 45%.

4.2 Main innovations

4.2.1 Whereas previous studies on watersheds to rivers have focused mainly on specific C species and on individual drivers of carbon export, this thesis has comparatively explored the relative influence of the ensemble of topography and land cover variables on total riverine carbon export and its main components, scaling from individual watersheds to the globe. At the regional scale, an examination of variance partitioning in our models revealed that topography is slightly more important than land-cover in explaining the variance in DIC export (19% vs 15%), whereas land-cover is much more important than topography in determining DOC export (44% vs 18%). This difference between topography and land cover in controlling DOC and DIC exports to rivers would lead to the changes in magnitude and/or composition of total carbon export because of the difference in anthropogenic impacts on the two categories of driving forces. Accordingly, the trends in total carbon and its

components exported from watersheds could be predicted based on the degree of anthropogenic disturbances.

4.2.2 This thesis has sketched an integrated view of total carbon export from boreal watersheds to river systems through exploring the spatial and temporal variations in total carbon and its components (DOC, DIC, POC, CO_2 and CH_4) exported from the boreal landscape. This study not only explored the intra-annual variation in the magnitude and composition of total carbon exported from the boreal watersheds also compared the total carbon between the neighboring sub-regions that are characterized by different landscapes (James Bay is dominated by peatlands, while in Abitibi beaver damming is ubiquitous along streams), and thus developed a better understanding of the spatial and temporal variations in carbon export to river systems at a regional scale.

4.2.3 This thesis reports a re-estimate of global riverine carbon export to the oceans based on the most extensive global C dataset to date. This global study yields a new global riverine carbon export rate of 0.68±0.05 Pg C yr^{-1} to the oceans, 24% lower than the widely-accepted value of 0.9 yr^{-1} through narrowing the uncertainties in the previous estimations. Through a series of multiple linear regression analyses, the relative importance of different natural and anthropogenic drivers of riverine carbon

exported in different forms from land to sea has been further clarified. Especially, we found that %croplands in the watershed like runoff (though runoff can explain 40-58% variance in riveerine carbon export) is an important variable influencing all the different carbon forms (DOC, DIC and POC). In particular, the current cropland coverage of the global terrestrial area is around 11%, having huge potential of cropland expansion, while the global runoff has increased less than 4% since 1880 (Labat et al., 2004; Dai et al., 2009), highlighting human activities, especially cropland expansion around the world, would become a very important variable influencing the global riverine carbon export to the oceans in the future.

4.3 Important implications

The finding that topography is slightly more important than land-cover in explaining the variance in DIC export (19% vs 15%), whereas land-cover is much more important than topography in determining DOC export (44% vs 18%) from the watershed to rivers implies that how to effectively and rationally use and manage land resources would be very important to direct the trend of riverine carbon export from watersheds to aquatic ecosystems scaling from a catchment to the globe. The average of total carbon exported from the boreal watersheds to the river systems (15.6 gC m^{-2} yr^{-1}) is in the order of 5 to 11% of the regional NPP, but of the same magnitude of the

Net Ecosystem Production that has been estimated for this type of landscape highlighting the need to integrate carbon export from watersheds to river systems into terrestrial carbon budgets in order to improve our understanding of landscape C sources and sinks within the boreal biome. Further, our re-analysis of the global export dataset resulted in a new estimate of annual global riverine carbon export to the oceans of 0.68 Pg yr^{-1}, which is significantly lower than current accepted figure of 0.9 Pg yr^{-1}, of which DOC, POC, DIC and PIC exports are 0.18, 0.07, 0.39 and 0.04 Pg yr^{-1}, respectively, imply that it is necessary to reassess the role and importance of carbon export from watershed to river systems in terrestrial and global carbon. The thesis has also contributed to narrowing down the uncertainties in the estimations of other C reservoirs, which is essential to better constrain the regional and global carbon budget. The finding that %cropland in the watershed is closely related to the riverine carbon export through the global analysis of riverine carbon export to the oceans further implies that human activities, especially cropland expansion, may be replacing the natural driving forces as the primary determinants of the magnitude and composition of both current and future transfers of carbon from land, through the hydrologic network, and ultimately reaching to sea, further indicating the importance of land use and management in controlling riverine carbon export from terrestrial to

aquatic ecosystems in the context of climate and human-induced environmental changes.

N.B. References cited in this chapter are presented at the end of the thesis.

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Appendix A

Supplementary Information For

A Global Analysis of Riverine Carbon Export to the Oceans

SI-1. List and source of landscape characteristics extracted for each catchment draining into the oceans

Data	Type	Citation
Runoff	Raster	Fetke, Balazs M. et al (2000). Global Composite Runoff Fields Based on Observed River Discharge and Simulated Water Balances. Complex Systems Research Center, University of New Hampshire. UNH-GRDC Composite Runoff Fields v1.0. Available at http://www.grdc.sr.unh.edu/.
Land Cover 2010	Raster	European Space Agency (ESA) – Climate Change Initiative (CCI). The Land Cover CCI Climate Research Data Package (CRDP). Land Cover Maps – v1.5 (2008-2012 epoch). Available at http://maps.elie.ucl.ac.be/CCI/viewer/download.php
Soil organic C (Top 0-30 cm)	Raster	Harmonized World Soil Database V1.2 Organic Carbon density. http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/
Carbonates	Polygon (Shapefile)	Williams & Ford. World map of carbonate rock outcrops v3.0. SGGES, University of Auckland, New Zealand. Available at http://web.env.auckland.ac.nz/our_research/karst/

SI-2. Land Cover categories amalgamation

The land cover classes provided by the ESA CCI land cover product (2010) contains 37 distinct categories. For the purposes of our carbon export model development, these were simplified to only 5 classes using the following amalgamation:

% Forests = Sum of (

Tree cover, broadleaved, deciduous, closed to open (>15%)

Tree cover, broadleaved, deciduous, open (15-40%)
Tree cover, broadleaved, evergreen, closed to open (>15%)
Tree cover, flooded, fresh or brakish water
Tree cover, flooded, saline water
Tree cover, mixed leaf type (broadleaved and needleleaved)
Tree cover, needleleaved, deciduous, closed (>40%)
Tree cover, needleleaved, deciduous, closed to open (>15%)
Tree cover, needleleaved, deciduous, open (15-40%)
Tree cover, needleleaved, evergreen, closed (>40%)
Tree cover, needleleaved, evergreen, closed to open (>15%)
Tree cover, needleleaved, evergreen, open (15-40%)
Tree or shrub cover)

%Croplands = Sum of (
Cropland, irrigated or post-flooding
Cropland, rainfed
Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%))

%Wetlands = Sum of (
Tree cover, flooded, fresh or brakish water
Tree cover, flooded, saline water
Shrub or herbaceous cover, flooded, fresh/saline/brakish water)

%Shrublands= Sum of (
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)"),
Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)
Shrub or herbaceous cover, flooded, fresh/saline/brakish water"
Shrubland,
Shrubland deciduous,
Shrubland evergreen,
Sparse herbaceous cover (<15%)
Sparse shrub (<15%)
Sparse vegetation (tree, shrub, herbaceous cover) (<15%)

% Water bodies = Water bodies

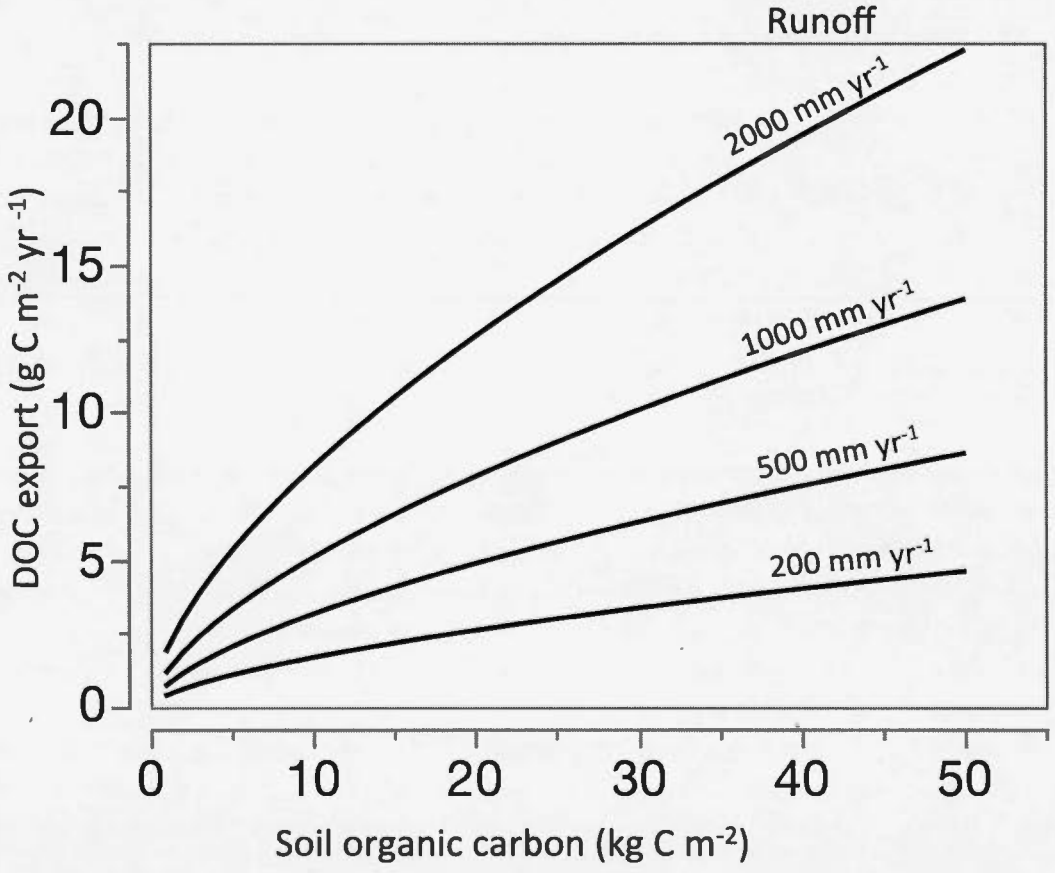
SI-3. Additional Water Residence Time (AWRT) from large freshwater reservoirs

We developed the metric AWRT to act as a proxy for the amount of additional time water stays within a catchment because of the added volumes contained in large freshwater reservoirs. This was accomplished by summing the reservoir water volume capacities of all reservoirs within each catchment and dividing by the average annual runoff over the catchment. We used the geolocated GRanD (Global Reservoir and Dam) database available at http://www.gwsp.org/products/grand-database.html .

SI-4. Average DOC export = (Runoff, SOC)

The generalized DOC export from a catchment can derived by solving the multivariate models presented in Table 1 of the main text as a function of only Runoff and SOC and replacing the other variables with their mean values in our data set. The resulting equation as illustrated as a family of curves representing the relationship between DOC export and Soil Organic Carbon for different runoff values. For SOC>10 kg m^{-2} , the relationships are approximately linear (Fig. SI-4.1) suggesting that DOC yield can be roughly considered as a first-order reaction with the SOC reservoir.

Figure S4.1 . Relationship between DOC export and Soil Organic Carbon (kg C m^{-2}) for different levels of annual runoff (mm yr^{-1})


Runoff
2000 mm yr-1
1000 mm yr-1
500 mm yr-1
200 mm yr-1
DOC export (g C m-2 yr-1)
0
5
10
15
20
0
10
20
30
40
50
Soil organic carbon (kg C m-2)

SI-5. Complete Data set used in this study.

Rivers	Reference	Rivers	Reference
A la Baleine	Rosa et al., 2012; Hudon et al., 1996	Brahmani	Meybeck and Ragu, 1996
Abitibi	Sheehan, 1989; SENES, 2013	Brahmaputra	Meybeck and Ragu, 1996
Abra	Dulay, 2005; EMB-CAR, 2013	Brantas	Aldrian et al., 2008
Adige	UNEP, 2003	Brazos (Tex)	Stets & Striegl, 2012
Adour	Guemuen et al., 2002; Point et al., 2007;	Breede	N. VAN BINSBERGEN, 2011
Agano	Büsser et al., 2012	Broadback	Mundy et al., 2010; Rosa et al., 2012; Clair et al.,
Agno	San Diego-McGlone et al., 1998	Buffalo Bayou	Stets & Striegl, 2012
Agusan	Breward, 1996	Buller	Carey et al., 2005
Ahtava	Kulinski and Pempkowiak, 2011	Burdekin	Meybeck and Ragu, 1996
Akheloos	UNEP, 2003; Skoulikidis et al., 1998	Burnside	Chouinard and Milburn, 1995
Alafia	Stets & Striegl, 2012	Buyuk Mende	Meybeck and Ragu, 1996
Alazeya	Dolman et al., 2012; Gordeev et al., 1996	Bzyb	Meybeck and Ragu, 1996
Albany	Meybeck and Ragu, 1996	Cagayan	Meybeck and Ragu, 1996
Aliakmon	Skoulikidis et al., 1998; UNEP, 2003	Cape Fear	Avery Jr. et al., 2003; Stets & Striegl, 2012
Alsea	Stets & Striegl, 2012	Cauweri	Sarma et al., 2012
Alsek	Ministry of Environmen of BC, 1996; Eckert et	Cavally	Meybeck and Ragu, 1996
Altamaha	Stets & Striegl, 2012	Cedar	Stets & Striegl, 2012
Amazon	Richey et al., 1990; Araujo et al., 2014	Ceyhan (Seyhi	Meybeck and Ragu, 1996
Ameca	Meybeck and Ragu, 1996	Changhua	Chen&Chen, 1992
Amgerman	Kulinski and Pempkowiak, 2011	Changjiang	Cai et al., 2008; Wang et al.,2012
Amguema	Gordeev et al., 1996	Chao Phrya	Meybeck and Ragu, 1996
Amur	Moon et al., 2009	Charles	Stets & Striegl, 2012
Anabar	Gordeev et al., 1996	Chehalis	Stets & Striegl, 2012
Anadyr	Meybeck and Ragu, 1996	Chickahominy	Stets & Striegl, 2012
Anderson	Meybeck and Ragu, 1996	Chico	Brunet et al., 2005
Androscoggin	Stets & Striegl, 2012	Chikugo	Liu et al., 2010
Ankobra	Yidana et al., 2008	Cho Shui Chi	Pan, 2012
Apalachicola	Stets & Striegl, 2012	Choctawatche	Stets & Striegl, 2012
Appomattox	Stets & Striegl, 2012	Chubut	Brunet et al., 2005
Approuague	Meybeck and Ragu, 1996	Churchill (Atl)	Clair et al., 1994, 2013
Arcens	UNEP, 2003	Churchill (Huc	Gransko et al., 2007
Arnaud	Hudon et al., 1996	Cimanuk	Meybeck and Ragu, 1996
Arno	UNEP, 2003	Citanduy	Meybeck and Ragu, 1996
Ashburton	URS, 2014	Citarum	Meybeck and Ragu, 1996
Atran	Kulinski and Pempkowiak, 2011	Clarence	Meybeck and Ragu, 1996
Atrato	Restrepo & Kjerfve, 2004	Clutha	Meybeck and Ragu, 1996
Attawapiskat	OCWA, 2001; Despault & Branfireun, 2014	Colorado (Arg	Brunet et al., 2005
Aucilla	Stets & Striegl, 2012	Colorado (Ari)	Stets & Striegl, 2012
Aude	UNEP, 2003	Colorado (Tex	Stets & Striegl, 2012
Auraioki	Räike et al., 2012	Columbia	Stets & Striegl, 2012
Aux Feuilles	Hudon et al., 1996	Colville	Gordeev et al., 1996
Aux Outardes	Hudon et al., 1996; Clair et al., 2013	Comoe	Meybeck and Ragu, 1996
Aux Rochers	Hudon et al., 1996	Connecticut	Stets & Striegl, 2012; Hossler et al., 2013
Axios	UNEP, 2003; skoulikidis et al., 1998;	Coosawhatchi	Stets & Striegl, 2012
Babage	Meybeck and Ragu, 1996	Copper	Meybeck and Ragu, 1996
Back	Chouinard and Milburn, 1995	Coppermine	Rollo, 2003; Chouinard and Milburn, 1995
Baker	Meybeck and Ragu, 1996	Corneille	Hudon et al., 1996
Ban Pakong	Meybeck and Ragu, 1996	Cross	Edet et al., 2013
Bandama	Meybeck and Ragu, 1996	Cunene	Meybeck and Ragu, 1996
Barito	Meybeck and Ragu, 1996	Cuyuni	Tosiani et al., 2004
Barumun	Meybeck and Ragu, 1996	Dalalven	Meybeck and Ragu, 1996
Berbice	Meybeck and Ragu, 1996	Daling	Xia & Zhang, 2011
Betsiamites	Clair et al., 2013	Daly	Robson et al., 2010
Betsiboka	Ralison et al., 2008; Marwick et al.,2014	Damodar (Hoo	Meybeck and Ragu, 1996
Biobio	Vargas et al., 2013	Danube	Meybeck and Ragu, 1996
Blackstone	Nixon et al., 1995; Stets & Striegl, 2012	Daugava	Kulinski and Pempkowiak, 2011
Botorpsström	Kulinski and Pempkowiak, 2011	Dee	Hope et al., 1997; Dawson et al., 2009

Delangersan	Kulinski and Pempkowiak, 2011	Haast	Carey et al., 2005
Delaware	Stets & Striegl, 2012 ; Hossler& Bauer, 2013	Hai Ho	Meybeck and Ragu, 1996
Deseado	Brunet et al., 2005	Han	Lee et al., 2007; Kim et al., 2007
Dnepr	Meybeck and Ragu, 1996	Hanjiang	Meybeck and Ragu, 1996
Dnestr	Meybeck and Ragu, 1996	Harricana	Rosa et al., 2012; Clair et al., 2013
Doce	PETRUCIO, 2003	Harsit	Bayram et al., 2011
Don	Meybeck and Ragu, 1996	Hayes	Chouinard and Milburn, 1995; Gransko et al., 2007;
Dordogne	Meybeck and Ragu, 1996	Helgean	Kulinski and Pempkowiak, 2011
Douro	Magalhães et al., 2008	Helleh	Meybeck and Ragu, 1996
Drammenselva	Meybeck and Ragu, 1996	Herault	UNEP, 2003
Du Nord	Hudon et al., 1996	Herbert	Alongi et al., 1998
Dumai	Alkhatib et al., 2007	Hillsborough	Stets & Striegl, 2012
Eagle (NL, Ca)	Clair et al., 1994	Hoh	Stets & Striegl, 2012
Eastmain	Schneider-Vieira et al., 1994; Teodoru et al.,	Hong	Meybeck and Ragu, 1996
Ebro	UNEP, 2003; Gómez-Gutiérrez et al., 2006;	Housatonic	Stets & Striegl, 2012
Edisto	Celeste et al., 2012; Stets & Striegl, 2012	Hsiukuluan	Pan, 2012
Eel	Muholland&Watts, 1982; Stets & Striegl, 2012	Huai	Wu et al., 2011
Elbe	Tockner et al., 2009; Pätsch and Lenhart, 2011	Hualien	Pan, 2012
Ellice	Chouinard and Milburn, 1995	Huang He	Gu et al., 2009; Ran et al., 2013; Wang et al., 2012
Elwha	Stets & Striegl, 2012	Hudson	Hossler& Bauer, 2013
Emån	Kulinski and Pempkowiak, 2011	Hun (Daliao)	Xia & Zhang, 2011
Ems	Patsch and Lenhart, 2011; Ludwig et al., 1996	Hunter	Hitchcock et al., 2010
Escambia	Stets & Striegl, 2012	Iijoki	Kulinski and Pempkowiak, 2011
Escatawpa	Stets & Striegl, 2012	Indalsalven	Kulinski and Pempkowiak, 2011
Escoumins	Hudon et al., 1996	Indigirka	Gordeev et al., 1996; Lobbes et al., 2000; Dittmar &
Essequibo	Pereira et al., 2014	Indus	Meybeck and Ragu, 1996
Etamamiou	Hudon et al., 1996	Inguri	Meybeck and Ragu, 1996
Eurajoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Irbe	K?avi?? et al., 2011
Evros	Skoulikidis et al., 1998; Skoulikidis, 1989;	Irrawaddy	Bird et al., 2008
Filyos	Meybeck and Ragu, 1996	Ishikari	Jha & Masao, 2013; Alam et al., 2007; Alam et al.,
Fitzroy East	Ford et al., 2005	Iwaki	Iwata et al., 2013
Flinders	Meybeck and Ragu, 1996	Jacui	Meybeck and Ragu, 1996
Fly	Goni et al., 2006; Ferguson et al., 2011; Alin et	James	Stets & Striegl, 2012
Fraser	Clair et al., 2013; Voss et al., 2014	Jiulong	Cai et al.1998; Qiu and Ye, 2013
Fuchun Jiang	Ren et al., 2006; Cai, 2006; Wu et al., 2011	Jubba	Meybeck and Ragu, 1996
Fyrisan	Ledesma et al., 2012	Jucar	Meybeck and Ragu, 1996
Gallegos	Skoulikidis et al., 1998; Brunet et al., 2005	Kalajoki	Räike et al., 2012; Kulinski and Pempkowiak, 2011
Gambia	Lesack et al., 1984	Kalga	Pokrovsky & Schott, 2002
Gamtoos	Meybeck and Ragu, 1996	Kalix	Humborg et al., 2004; Kulinski and Pempkowiak,
Ganges	Meybeck and Ragu, 1996	Kamchatka	Pokrovsky & Schott, 2002
Garonne	Schäfer et al., 2006; Veyssy et al., 1999;	Kaoping	Pan, 2012
Gauja	Klaviņš et al., 2011	Kapuas	Anshari et al., 2010
Gediz	Bizsel et al., 2011; Odemis and Evrendilek,2007	Karjaanjoki	Räike et al., 2012
George	Hudon et al., 1996	Karoon	Fooladvand et al., 2011
Gide	Kulinski and Pempkowiak, 2011	Kazan	Chouinard and Milburn, 1995
Gizhiga	Dolman et al., 2012	Kelantan	Meybeck and Ragu, 1996
Glama	Meybeck and Ragu, 1996	Kem	Pokrovsky & Schott, 2002
Godavari	Sarin et al., 2002; Balakrishna&Probst, 2005;	Kemijoki	Kulinski and Pempkowiak, 2011; Räike et al., 2012
Godbout	Hudon et al., 1996	Kennebec	Cronan, 2012; Stets & Striegl, 2012
Gota	Kulinski and Pempkowiak, 2011	Keret	Pokrovsky & Schott, 2002
Gr Baleine	Rosa et al., 2012; Clair et al., 2013; Hudon et	Khatanga	Gordeev et al., 1996
Grey	Carey et al., 2005	Kiiminginjoki	Kulinski and Pempkowiak, 2011; Räike et al., 2012
Gros Mecatina	Hudon et al., 1996	Kikori	Meybeck and Ragu, 1996
Guadalupe	Stets & Striegl, 2012	Kinabatangan	Harun, 2013
Gualdalquivir	Meybeck and Ragu, 1996	Kiskonjoki	Kulinski and Pempkowiak, 2011; Räike et al., 2012
Guayas	Meybeck and Ragu, 1996	Kiso	Sugimoto et al., 2006; Liu et al., 2010

Kitakami	Büsser et al., 2012	Mazaruni	Meybeck and Ragu, 1996
Kizil Irmark	Meybeck and Ragu, 1996	Medjerda	Meybeck and Ragu, 1996
Klamath	Stets & Striegl, 2012	Medway	Clair et al., 1994
Kobuk	Meybeck and Ragu, 1996	Mekong	Noh et al.,2013
Kodori	Meybeck and Ragu, 1996	Menjiang	Zhu et al., 2012; Yang et al., 2008
Kokemaenjoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Merikarvia	Kulinski and Pempkowiak, 2011
Koksoak	Rosa et al., 2012; Clair et al., 2013	Mermentau	Stets & Striegl, 2012
Kola	Pekka et al., 2008	Merrimack	Meybeck and Ragu, 1996
Kolyma	Lobbes et al., 2000; Gordeev et al., 1996;	Meuse	Servais et al., 1989; Cleven et al., 2005
Konkoure	Meybeck and Ragu, 1996	Mezen	Gordeev et al., 1996; Lobbes et al., 2000; Dittmar &
Krishna	Sarma et al., 2012	Minho	Meybeck and Ragu, 1996
Kuban	Meybeck and Ragu, 1996	Mississippi	Stets & Striegl, 2012
Kuivajoki	Kulinski and Pempkowiak, 2011	Mitchell	Meybeck and Ragu, 1996
Kushiro	Alam et al., 2012	Mobile	Stets & Striegl, 2012
Kuskokwim	Meybeck and Ragu, 1996	Mogami	Büsser et al., 2012
Kuzema	Pokrovsky & Schott, 2002	Moisie	Hudon et al., 1996; Naiman and Link, 1997; Clair et
Kymijoki	Kulinski and Pempkowiak, 2011	Moose	Sheehan,1989
Kyrönjoki	Räike et al., 2012	Morrumsan	Kulinski and Pempkowiak, 2011
La Grande	Schneider-Vieira et al., 1994; Rosa et al., 2012;	Motagua	Meybeck and Ragu, 1996
Lagan	Kulinski and Pempkowiak, 2011	Motala	Kulinski and Pempkowiak, 2011
Lahave	Clair et al., 1994	Moulouya	Iavazzo et al., 2012
Lanyang	Kao&Liu, 1996,1997; Pan, 2012	Murray	Cartwright, 2010
Lapuanjoki	Räike et al., 2012	Musa	Klavins, 2013
Lapväärtinjoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Musi	Meybeck and Ragu, 1996
Lavaca	Stets & Striegl, 2012	Musquaro	Hudon et al., 1996
Leba	Niemirycz et al., 2006	Myakka	Stets & Striegl, 2012
Leichhardt	Noller et al., 2012	n Dvina	Gordeev et al., 1996; Dittmar & Kattner, 2003
Lena	Gordeev et al., 1996; Dittmar & Kattner, 2003;	Nadym	Dolman et al., 2012
Lestijoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Nagavali	Sarma et al., 2012
Letniya North	Pokrovsky & Schott, 2002	Nandu	Chen&Chen, 1992
Liao	Xia & Zhang, 2011; Yu et al., 2015	Napa	Stets & Striegl, 2012
Lielupe	K?avi?? et al., 2011	Narmada	Sharma&Subramanian, 2008; Sarma et al., 2012
Liioki	Räike et al., 2012	Närpiönjoki	Räike et al., 2012
Limpopo	Oberholster et al, 2010	Narraguagus	Stets & Striegl, 2012
Liungan	Kulinski and Pempkowiak, 2011	Narva	Kulinski and Pempkowiak, 2011
Liungbyan	Kulinski and Pempkowiak, 2011	Nastapoca	Granskok et al., 2007
Loire	Niemirycz et al., 2006	Natashquan	Hudon et al., 1996; Clair et al., 2013
Lorillard	Chouinard and Milburn, 1995	Navidad	Stets & Striegl, 2012
Los Angeles	Stets & Striegl, 2012	Neches	Stets & Striegl, 2012
Loukkos	EL Morhit et al., 2013	Negro (Arg)	Brunet et al., 2005
Louros	Ovezikoglou et al., 2003	Nehalem	Stets & Striegl, 2012
Luan	xia & Zhang, 2011	Nelson	Schneider-Vieira et al., 1994; Rosa et al., 2012; Clair
Luga	Meybeck and Ragu, 1996	Nemanus	Kulinski and Pempkowiak, 2011; Tockner et al., 2009
Lulealven	Humborg et al., 2004; Kulinski and	Nestos	Skoulikidis et al., 1998; Skoulikidis, 1989
Lupawa	Niemirycz et al., 2006	Nethravati	Tript et al., 2013; Sarma et al., 2012
Lyckebyan	Kulinski and Pempkowiak, 2011	Neuse	Davis et al., 1978; Hope et al., 1994;Bales et al.,
Macdonald	Hudon et al., 1996	Neva	Kulinski and Pempkowiak, 2011
Mackenzie	Clair et al., 2013	Neyyar	Maya et al., 2013
Mad	Stets & Striegl, 2012	Niger	Esser&Kohlmaier, 1991; Harrison et al., 2005; Araujo
Magdalena	Lewis et al., 1995; Jujnovsky et al., 2010	Nile	Meybeck and Ragu, 1996
Magpie	Hudon et al., 1996	Nissan	Kulinski and Pempkowiak, 2011
Mahakam	Meybeck and Ragu, 1996	Nottaway	Mundy et al., 2010; Clair et al., 2013
Mahanadi	Panigrahy and Raymahashay, 2005; Sarma et	Nueces	Stets & Striegl, 2012
Maipo	Meybeck and Ragu, 1996	Nykopingsan	Kulinski and Pempkowiak, 2011
Manavgat	Meybeck and Ragu, 1996	Nyong	Brunet et al., 2009
Manicouagan	Hudon et al., 1996; Clair et al., 2013	Ob	Gordeev et al., 1996; Dittmar & Kattner, 2003
Maroni	Sondag et al., 2010	Ochlockonee	Stets & Striegl, 2012
Matamek	Hudon et al., 1996	Odra	Sienak, 1999

Ogeechee	Stets & Striegl, 2012	Rambla Del	Garcia-Pintado et al., 2007
Ogooue	Meybeck and Ragu, 1996	Ranealven	Humborg et al., 2004
Olenek	Gordeev et al., 1996; Lobbes et al., 2000;	Rangitikei	Carey et al., 2005
Olfusa	Meybeck and Ragu, 1996	Rappahannoc	Stets & Striegl, 2012
Olomane	Hudon et al., 1996	Raritan	Stets & Striegl, 2012
Omoloy	Gordeev et al., 1996; Lobbes et al., 2000	Reda	Niemirycz et al., 2006
Onega	Gordeev et al., 1996	Rega	Niemirycz et al., 2006
Orange	Beusen et al., 2005; Harrison et al., 2005;	Rhine	Niemirycz et al., 2006
Orb	UNEP, 2003	Rhone	Sempéré et al., 2000
Ore	Kulinski and Pempkowiak, 2011	Rianila	Abril et al., 2015; Marwick et al., 2014
Orinoco	Lewis and Saunders, 1989; Paolini, 1995;	Ricklean	Kulinski and Pempkowiak, 2011
Oueme	Meybeck and Ragu, 1996	Rio Grande	Stets & Striegl, 2012
Oulujoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Rioni	Meybeck and Ragu, 1996
Oyapok	Sondag et al., 2010	Roanoke	Stets & Striegl, 2012 ; Hossler& Bauer, 2013
Paimionjoki	Räike et al., 2012	Rogue	Stets & Striegl, 2012
Palar	Prabhahar et al., 2012	Romaine	Hudon et al., 1996; Clair et al., 2013
Pamunkey	Hossler& Bauer, 2013	Ronnea	Kulinski and Pempkowiak, 2011
Panuco	Meybeck and Ragu, 1996	Rufiji	Meybeck and Ragu, 1996
Paraiba Do	Jennerjahn et al., 2010; Araujo et al., 2014	Rupert	Mundy et al., 2010; Rosa et al., 2012; Clair et al.,
Parana	Depetris & Kempe, 1993	Russian	Stets & Striegl, 2012
Parnaiba	Meybeck and Ragu, 1996	Sabarmati	Sarma et al., 2012
Pars?Ta	Niemirycz et al., 2006	Sabine	Stets & Striegl, 2012
Pascagoula	Stets & Striegl, 2012	Saco	Stets & Striegl, 2012
Patuxent	Stets & Striegl, 2012	Sacramento	Stets & Striegl, 2012
Pawcatuck	Stets & Striegl, 2012	Saguenay	Hudon et al., 1996
Pawtuxet	Nixon et al., 1995	Saint	Hudon et al., 1996
Peace	Stets & Striegl, 2012	Saint John	Clair et al., 2013
Pearl	Duan et al., 2007,2006; Stets & Striegl, 2012	Saint John's	Stets & Striegl, 2012
Pechora	Gordeev et al., 1996; Dittmar & Kattner, 2003	Saint	Hudon et al., 1996; Clair et al., 2013
Pee Dee	Stets & Striegl, 2012	Sakarya	Tockner et al., 2009
Peel	Water Resources Division of Canada, 2002	Salaca	Klaviņš et al., 2011
Peinan	Pan, 2012	Salinas	Stets & Striegl, 2012
Penner	Sarma et al., 2012	Salmon	Clair et al., 1994
Penobscot	Cronan, 2012; Stets & Striegl, 2012	Salween	Bird et al., 2008
Penzhina	Meybeck and Ragu, 1996	San Bernard	Stets & Striegl, 2012
Perdido	Stets & Striegl, 2012	San Joaquin	Meybeck and Ragu, 1996
Perhonjoki	Kulinski and Pempkowiak, 2011; Räike et al.,	San Luis Rey	Stets & Striegl, 2012
Periyar	Meybeck and Ragu, 1996	Sanaga	Meybeck and Ragu, 1996
Petit Baleine	Hudon et al., 1996; Gransko et al., 2007	Santa Ana	Stets & Striegl, 2012
Petit	Hudon et al., 1996	Santa Clara	Masiello and Druffel,2001; Stets & Striegl, 2012
Pinios	Skoulikidis et al., 1998	Santa Cruz	Brunet et al., 2005
Pitalven	Humborg et al., 2004; Kulinski and	Santee	Meybeck and Ragu, 1996
Po	Tockner et al., 2009; Pettine et al., 1998;	Sao Francisco	Araujo et al., 2014
Pongoma	Pokrovsky & Schott, 2002	Sassandra	Meybeck and Ragu, 1996
Ponnaiya	Sarma et al., 2012	Satilla	Stets & Striegl, 2012
Pontax	Rosa et al., 2012	Savannah	Stets & Striegl, 2012
Porvoonjoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Scheldt	Abril et al., 2000
Potomac	Stets & Striegl, 2012 ; Hossler& Bauer, 2013	Seal	Meybeck and Ragu, 1996
Povuntnituk	Gransko et al., 2007	Sebangau	Moore et al., 2011
Pregolya	Meybeck and Ragu, 1996	Sebou	Meybeck and Ragu, 1996
Progo	Meybeck and Ragu, 1996	Seine	Meybeck and Ragu, 1996
Pur	Gordeev et al., 1996	Senegal	Martins and Probst,1991
Purari	Meybeck and Ragu, 1996	Sepik	Burns et al., 2008
Puyallup	Stets & Striegl, 2012	Serayu	Li et al., 1995
Pyasina	Dolman et al., 2012	Severn (Can)	OCWA, 2001
Pyhäjoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Severn (Gb)	Mantoura & Woodward, 1983
Queets	Stets & Striegl, 2012	Shannon	Meybeck and Ragu, 1996
Quinault	Stets & Striegl, 2012	Shatt El Arab	Meybeck and Ragu, 1996
Quoich	Chouinard and Milburn, 1995	Shinano	Büsser et al., 2012

Shuya	Pokrovsky & Schott, 2002	Tunguda	Pokrovsky & Schott, 2002
Siak	Baum et al., 2007	Tusket	Clair et al., 1994
Siikajoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Tyne	Baker & Spencer, 2004
Simojoki	Kulinski and Pempkowiak, 2011; Räike et al.,	Uda	Dolman et al., 2012
Sirppujoki	Kulinski and Pempkowiak, 2011	Ume-	Kulinski and Pempkowiak, 2011
Siuslaw	Stets & Striegl, 2012	Umpqua	Stets & Striegl, 2012
Skagit	Stets & Striegl, 2012	Urugury	Meybeck and Ragu, 1996
Skeena	Clair et al., 2013	Uskelanjoki	Kulinski and Pempkowiak, 2011; Räike et al., 2012
Skelleftalv	Humborg et al., 2004; Kulinski and	Usumacinta	Meybeck and Ragu, 1996
Skieselva	Meybeck and Ragu, 1996	Vamsadhara	Sarma et al., 2012
Skokomish	Stets & Striegl, 2012	Vantaanjoki	Räike et al., 2012
Slupia	Niemirycz et al., 2006	Var	UNEP, 2003
Smith	Stets & Striegl, 2012	Vellar	Sarma et al., 2012
Snohomish	Stets & Striegl, 2012	Venta	K?avi?? et al., 2011
Solo	Li et al., 1995	Ventura	Stets & Striegl, 2012
Spercheios	Skoulikidis et al., 1998; Kormas 2003&2004	Vizhas	Lobbes et al., 2000
St Mary's	Clair et al., 1994	Volta	Andah et al., 2003; Araujo et al., 2014
St. Marks	Stets & Striegl, 2012	Waiau	Carey et al., 2005
St. Marys	Stets & Striegl, 2012	Waikato	Meybeck and Ragu, 1996
Steinhatchee	Stets & Striegl, 2012	Waimakariri	Carey et al., 2005
Stikine	Clair et al., 2013	Waipaoa	Gomez et al., 2003
Strymon	Skoulikidis et al., 1998; UNEP, 2003	Waitaki	Meybeck and Ragu, 1996
Suannee	Meybeck and Ragu, 1996	Waitara	Carey et al., 2005
Subarnarekha	Sarma et al., 2012	Waitotara	Carey et al., 2005
Suriname	Meybeck and Ragu, 1996	Wanquan	Chen&Chen, 1992; Tian et al., 2010
Susitna	Meybeck and Ragu, 1996	Warnow	Freese et al., 2007
Susquehanna	Stets & Striegl, 2012; Hossler and Bauer, 2013	Watshishou	Hudon et al., 1996
Swan-Avon	Petrone, 2010	Wenjiao	Tian et al., 2010
Swarna	Tript et al., 2013	Weser	Meybeck and Ragu, 1996
Ta Chia Chi	Pan, 2012	Whangaehu	Carey et al., 2005
Taku	Neal, 2007	Whanganui	Carey et al., 2005
Tan Shui	Pan, 2012	Wieprza	Niemirycz et al., 2006
Tana (Ken)	Bouillon et al., 2007	Winisk	Gransko et al., 2007
Tapti	Sharma&Subramanian, 2008; Sarma et al., 2012	Wisla	Niemirycz et al., 2006; Kulinski and Pempkowiak,
Tar	Davis et al...1978; Bales et al., 2000; Lin et al.,	Withlacooche	Stets & Striegl, 2012
Taunton	Nixon et al., 1995	Wolf	Stets & Striegl, 2012
Tavignano	UNEP, 2003	Wu Chi	Pan, 2012
Taymyra	Dolman et al., 2012	Xiaolinghe	Xia & Zhang, 2011
Taz	Cochran et al., 1996; Gordeev et al., 1996	Yalu	Wang et al., 1998; Wu & Zhang, 2001
Teio	Meybeck and Ragu, 1996	Yana	Gordeev et al., 1996; Dittmar & Kattner, 2003;
Tenryu	Büsser et al., 2012	Yarra	Santos et al., 2012
Teshio	Naganuma&Seki, 1987; Alam et al., 2012	Yellow (US)	Stets & Striegl, 2012
Tet	UNEP, 2003	Yenisey	Gordeev et al., 1996; Dittmar & Kattner, 2003;
Tevere	Meybeck and Ragu, 1996	Yesilirmak	Jin et al., 2013; Duran and Suicmez,2007; Odemis and
Thames	Araujo et al., 2014; Neal et al., 1998	Yodo	Meybeck and Ragu, 1996
Thelon	Chouinard and Milburn, 1995	Yukon	Striegl et al., 2007
Thiorsa	Meybeck and Ragu, 1996	Zaire	Wang et al., 2013; Araujo et al., 2014
Tocantins	Lewis and Saunders, 1989,	Zambezi	Kunz, 2011
Tokachi	Alam et al., 2012; Büsser et al., 2012	Zhujiang	Yao et al., 2007
Tone	Büsser et al., 2012		
Tonnerre	Hudon et al., 1996		
Tornionioki	Kulinski and Pempkowiak, 2011		
Trent	Tipping et al., 1997		
Trinite	Hudon et al., 1996		
Trinity	Warnken & Santschi, 2004; Stets & Striegl,		
Tsengwen	Pan, 2012		
Tugur	Dolman et al., 2012		

Rivers	DOC mg/L	DIC mg/L	POC mg/L	PIC mg/L	TOC mg/L	TIC mg/L	Bas in Area (km2)	DOCex g/m2/yr	DICex g/m2/yr	POCex g/m2/yr	PICex g/m2/yr	TOCex g/m2/yr	TICex g/m2/yr	Latitude	Longitude	Continent	River length (km)	elevation(m)	river gradient (‰)	Bas in Slope (°)	Annual mean Temp (C)	runoff(mm)	Carbonates (%)	Urbans (%)	Water bodies (%)	Forest (%)	Cropland (%)	wetland (%)	Soil organic C (kg m-2)
A la Baleine	3.23	2.80	0.17		3.39		31800	1.85	1.60	0.10		1.94		58.02	-67.69	NAM				0.14	-5.6	572	0	0.0	9.9	55.6	0.0	0.9	18.3
Abitibi	12.07	6.90	0.64		12.70		27500	5.43	3.11	0.29		5.72		51.03	-80.92	NAM	450	250	0.56	0.08	0.6	450	11.1	0.1	2.1	75.4	1.3	12.9	12.3
Abra	6.25						5100	15.93						17.56	120.45	ASI	88	2800	31.82	6.61	23.2	2549	0	0.7	0.6	48.0	38.6	0.0	3.8
Adige	1.93	24.80	0.77		2.70		12000	1.17	15.07	0.47		1.64		45.14	12.30	EUR	410	2500	6.10	0.86	6.1	608	50.0	6.8	0.3	44.3	23.9	0.1	4.8
Adour	3.17	16.72	2.17		5.34		17000	2.00	10.52	1.37		3.36		43.53	-1.51	EUR	340	2800	8.24	2.45	11.3	629	16.7	3.3	0.3	34.9	36.3	0.0	4.9
Agano	1.38	22.00					7710	2.23	35.63					37.90	139.15	ASI	210	2500	11.90	1.52	9.2	1620	0	1.2	2.1	45.8	3.2	0.0	11.5
Agno	4.95	3.32	0.55		5.49		6167	5.55	3.72	0.62		6.16		16.03	120.21	ASI	275	1745	6.35	5.45	25	1121	0	2.2	0.9	18.3	33.6	0.6	3.9
Agusan	8.17	25.60	0.91		9.07		11300	28.91	90.61	3.21		32.12		9.00	125.53	ASI	350	45	0.13	1.83	25.3	3540	0	0.2	0.5	35.3	59.7	0.1	4.0
Alitava	13.11	2.40	0.69		13.80		2030	3.23	0.59	0.17		3.40		63.65	22.82	EUR		100		1.43	2.4	246	0	1.8	7.6	67.0	14.1	4.7	18.2
Akheloos	1.42	30.60	0.48		1.90		5540	1.46	31.32	0.49		1.95		38.36	21.11	EUR				4.32	12.4	1023	50.0	1.0	4.6	35.8	18.3	0.0	2.6
Alafia	29.49		4.58		34.06	14.74	868	5.22		0.81		6.03	2.61	27.86	-82.39	NAM				0.11	22.3	177	100	18.0	4.6	26.1	5.8	16.0	10.2
Alazeya	5.24	3.59	2.61		7.85		68000	0.68	0.46	0.34		1.02		70.83	153.66	ASI	1600	200	0.13	0.61	-13.2	129	0	0.0	12.6	42.2	0.0	8.2	10.2
Albany	8.10	16.70	0.90		9.00		134000	2.66	5.48	0.30		2.96		52.13	-82.06	NAM	975	200	0.21	0.05	-0.5	328	35.2	0.0	4.9	70.8	0.0	19.3	20.8
Alakmon	1.84	43.32	0.71		2.55		9500	0.81	19.15	0.31		1.13		40.49	22.63	EUR	310	2200	7.10	0.74	11	442	0	1.7	1.6	24.2	50.7	0.0	3.0
Alsea					2.08	3.91	865					3.21	6.03	44.42	-124.01	NAM				2.44	10	1543	0	0.0	0.0	91.0	0.0	0.0	10.1
Alsek	0.65	17.60	0.03		0.68	18.39	28000	0.62	16.85	0.03		0.65	17.6	59.19	-138.50	NAM	210	3000	14.29	1.20	-3.5	957	0	0.0	2.5	24.8	0.0	4.2	2.6
Altamaha	9.88	5.38	0.91		10.79		35200	3.03	1.65	0.28		3.31		31.38	-81.54	NAM	220	370	1.68	0.06	17.6	307	55.6	4.1	0.7	71.0	6.7	4.7	3.5
Amazon	4.69	6.50	2.65		7.35		6112000	5.06	7.01	2.86		7.92		0.05	-50.66	SAM	6280	5500	0.88	0.18	24.6	1078	0	0.1	1.7	84.4	4.2	2.9	5.9
Ameca		17.70					12000		4.43					20.68	-105.28	NAM	230	2600	11.30	3.38	20.2	250	0	0.3	0.2	60.0	17.9	0.0	5.3
Amgerman	6.53	3.05	0.69		7.22		31700	2.54	1.18	0.27		2.80		62.92	17.85	EUR	440	2300	5.23	0.68	1.2	388	0	0.2	6.2	63.2	0.3	10.1	18.3
Amguema	6.56	4.50	0.34		6.90		29600	2.04	1.40	0.10		2.14		67.95	-177.55	ASI	498	175	0.35	2.78	-11	311	0	0.0	1.1	0.0	0.0	0.0	4.6
Amur	10.40	5.70	0.41		10.81		1885000	1.90	1.04	0.08		1.97		53.21	139.86	ASI	4352	2000	0.46	0.22	-1.4	182	4.9	0.7	1.5	56.2	17.7	1.0	7.8
Anabar	4.85	6.40	0.26		5.10		78800	0.94	1.24	0.05		0.99		73.09	113.58	ASI	940	500	0.53	0.56	-13.4	194	39.0	0.0	0.6	40.1	0.0	0.6	6.9
Anadyr	7.13	3.30	0.36		7.49		200000	2.14	0.99	0.11		2.25		64.82	175.91	ASI	1100	680	0.62	0.22	-11.3	300	0	0.0	1.0	0.4	0.0	2.5	6.9
Anderson		27.50					48000		2.02					69.66	-128.84	NAM	750	200	0.27	0.68	-10.2	74	24.4	0.0	9.0	17.8	0.0	0.4	14.2
Androscoggin						2.83	8451						2.25	43.93	-69.90	NAM				0.18	4.7	795	50.0	2.0	4.6	20.1	0.5	0.1	9.1
Ankobra		11.96					8272		9.80					4.91	-2.27	AFR	190	330	1.74	3.32	26.1	820	0	0.5	0.1	24.5	73.6	0.2	3.5
Apalachicola	7.87	7.76	0.60	1.43	8.47	9.19	49728	2.87	2.83	0.22	0.52	3.09	3.35	29.74	-84.99	NAM	880	1100	1.25	0.24	17.7	365	58.3	4.5	1.4	64.5	14.6	5.2	3.7
Appomattox	5.86		2.34		8.20	6.01	3476	1.58		0.63		2.21	1.62	37.31	-77.30	NAM				0.05	13.5	270	0	3.0	0.8	32.6	2.0	1.1	3.6
Approuague		1.80					10200		2.05					4.53	-51.95	SAM	280	100	0.36	0.05	25.1	1137	0	0.0	0.4	99.4	0.0	1.1	3.6
Argens	2.40						2600	0.35						43.41	6.73	EUR	116			5.04	12.9	146	100	7.8	0.0	60.4	23.0	0.0	4.4
Arnaud	1.37	1.40					48500	0.58	0.60					59.99	-70.11	NAM	380	200	0.53	0.47	-7.7	425	7.7	0.0	11.7	0.2	0.0	0.0	1.4

Arno	4.36	54.50	1.74		6.10		8200	1.12	13.96	0.45		1.56		43.68	10.28	EUR	251	1700	6.77	2.13	12.9	256	0	9.5	1.5	44.9	39.6	0.1	3.8
Ashburton	9.25	15.00					82000	0.93	1.50					-44.05	171.80	OCE	640	1000	1.56	5.20	9.7	100	0	0.4	1.2	1.6	72.3	0.0	5.7
Atran	10.19	3.89	1.08		11.26		3342	5.49	2.09	0.58		6.07		56.89	12.48	EUR	240			0.06	6.2	539	0	1.7	4.9	73.6	12.5	1.9	15.8
Atrato		3.72					35700		8.44					7.92	-77.00	SAM	644	2000	3.11	2.15	24.8	2271	0	0.0	1.7	80.5	8.0	5.3	15.6
Attawapiskat	11.79	17.76					50200	4.63	6.98					52.95	-83.22	NAM	810			0.03	-1.7	393	40.0	0.0	4.3	57.0	0.0	34.1	27.5
Aucilla	24.29				19.64	6.88	2085	4.13			3.34		1.17	30.09	-83.99	NAM				5.13	19.8	170	100	0.0	4.5	75.2	0.0	61.8	4.7
Aude	3.30						4600	0.94						43.21	3.24	EUR	224			0.40	12.4	285	31.1	3.4	0.1	58.9	28.8	0.5	4.0
Aurajoki	14.93	6.75	1.35		16.28		874	4.30	1.95	0.39		4.69		60.44	22.24	EUR	70			6.51	4.3	288	0	5.7	0.1	36.6	51.8	1.8	12.2
Aux Feuilles	1.69	2.64					42500	0.74	1.16					58.78	-70.12	NAM	480	200	0.42	0.06	-6.6	438	0	0.0	10.8	1.9	0.0	0.0	1.4
Aux Outardes	5.48	5.76	0.34		5.82		18840	3.72	3.91	0.23		3.95		49.20	-68.50	NAM	480	1300	2.71	0.54	-2.2	678	0	0.0	7.4	77.3	0.0	1.3	9.3
Aux Rochers	6.99						4170	4.60						50.09	-66.98	NAM				0.14	-1.5	658	0	0.0	3.9	92.0	0.0	0.0	7.7
Axios	1.86	22.84	0.67		2.53		24700	0.31	3.83	0.11		0.42		40.60	22.85	EUR	310	2800	9.03	5.36	14.3	168	0	5.1	4.8	20.0	47.1	0.1	3.1
Babage		1.80					50000		0.04					69.21	-138.39	NAM	150	1000	6.67	6.99	-11.8	20	20.0	0.0	0.4	0.0	0.0	0.8	4.3
Back	3.62	2.17	0.21		3.83		107000	0.54	0.32	0.03		0.57		67.03	-95.29	NAM	960	200	0.21	0.62	-13.6	150	0	0.0	8.0	0.3	0.0	0.1	4.0
Baker		0.72					23500		0.97					-47.79	-73.50	SAM	310	1000	3.23	3.35	5	1343	0	0.1	9.3	20.1	3.2	0.0	4.7
Ban Pakong		1.32					17700		1.24					13.49	101.01	ASI	294	2965	10.09	1.25	27.3	938	0	2.5	0.4	15.0	70.1	0.1	5.6
Bandama		1.92					105000		0.21					5.17	-4.95	AFR	1050	100	0.10	0.05	26.5	110	0	0.5	0.8	34.8	40.0	0.0	3.1
Barito		5.76					66000		7.58					-3.38	114.51	ASI	650	800	1.23	0.39	26.1	1315	0	0.6	1.1	24.9	63.4	0.2	13.8
Barumun		1.44					16000		1.40					2.52	100.14	ASI	310	2400	7.74	0.15	25.4	975	8.3	0.0	0.2	29.1	63.1	4.8	8.9
Berbice		6.96					5100		2.18					6.28	-57.53	SAM	560	100	0.18	0.09	26.7	314	0	0.0	0.6	88.1	1.0	3.4	7.8
Betsiamites	6.80	5.16	0.35		7.15		18700	3.90	2.96	0.20		4.10		48.94	-68.70	NAM	440	200	0.45	0.36	-0.6	573	0	0.0	6.6	81.8	0.0	1.0	7.7
Betsiboka	0.50	4.34	0.88				49000	0.36	3.10	0.63				-16.06	46.58	AFR	520	1755	3.38	0.65	22.4	714	8.3	0.2	1.1	3.4	0.7	0.9	3.9
Biobio	2.58	2.40					24260	2.68	2.49					-36.81	-73.14	SAM	380	2000	5.26	1.80	10	1039	0	0.9	1.1	52.6	10.4	0.1	13.7
Blackstone	5.61	5.18	0.84		6.45		1222	3.53	3.26	0.53		4.06		41.87	-71.38	NAM				1.82	8.9	630	0	35.5	1.9	3.3	0.3	0.2	10.1
Botorpsströmme	12.35	5.50	0.65		13.00		999	2.47	1.10	0.13		2.60		57.61	16.60	EUR	75			2.96	6.8	200	0	1.3	12.4	65.9	13.0	0.3	7.9
Brahmani		9.96					39000		4.16					20.88	86.07	ASI	480	1000	2.08	0.24	25.5	418	0	0.7	1.7	8.5	72.2	0.1	2.8
Brahmaputra	2.85	7.44	2.60		5.45		580000	2.51	6.54	2.29		4.79		22.66	90.83	ASI	3000	5500	1.83	0.72	10.9	879	17.4	0.4	1.9	26.2	19.6	0.0	5.0
Brantas	19.86	15.56	2.41	2.52	22.27	18.08	11050	23.37	18.31	2.84	2.96	26.20	21.3	-7.56	112.86	ASI	320			1.54	24	1176	39.6	5.1	1.1	10.4	62.4	0.4	8.7
Brazos (Tex)	3.25	32.80	5.20	1.00	8.45	33.80	114000	0.14	1.45	0.23	0.04	0.37	1.49	28.90	-95.39	NAM	2060	1200	0.58	0.13	17.7	44	11.5	1.2	0.6	5.5	17.1	0.5	4.0
Breede	1.25	6.72					15300	0.17	0.89					-34.38	20.73	AFR	280	2300	8.21	4.00	15.8	132	50.0	0.7	0.9	7.8	27.9	0.0	1.5
Broadback	10.31	2.30	0.63		10.94		17000	6.25	1.39	0.38		6.63		51.35	-78.84	NAM	450	200	0.44	0.05	-1.2	606	0	0.0	10.1	49.4	0.0	33.6	17.9
Buffalo Bayou					21.99	10.14	751					11.19	5.16	29.74	-95.11	NAM				1.18	20.3	509	0	68.3	0.2	4.9	0.4	2.4	4.9
Buller	1.47		0.71		2.18		6400	2.90		1.40		4.30		-41.73	171.59	OCE	130	2400	18.46	0.26	8.7	1969	0	0.0	0.7	74.9	8.4	0.0	5.8
Burdekin		30.50					129000		2.06					-19.63	147.46	OCE	130	2400	18.46	0.42	22.5	67	4.3	0.0	0.3	9.6	0.3	0.0	3.1
Burnside	4.20	1.60	0.12		4.32		16800	1.00	0.38	0.03		1.03		66.87	-108.27	NAM	680	980	1.44	0.07	-12.8	238	0	0.0	11.4	0.6	0.0	0.1	3.9
Buyuk Menderes		50.40					19600		12.09					37.55	27.19	ASI	330	200	0.61	2.50	13.5	240	42.9	3.2	0.7	18.2	53.9	0.1	3.7
Bzyb		19.40					1510		38.90					43.20	40.31	ASI	110	3000	27.27	3.78	6.2	2005	22.9	0.5	0.4	68.1	9.7	0.1	5.1

Cagayan		11.80					27600		18.90					18.35	121.63	ASI	350	3100	8.86	1.41	24.4	1601	25.0	0.6	0.9	35.5	36.9	0.0	3.9
Cape Fear	8.63	3.20	0.72	0.37	9.35	3.57	13610	3.00	1.11	0.25	0.13	3.25	1.24	34.17	-77.96	NAM	320	300	0.94	0.67	15.7	348	0	4.7	0.7	37.9	22.3	10.7	5.7
Cauweri		37.92					88000		9.01					10.89	78.56	ASI	800	1300	1.63	0.46	25.2	238	0	1.5	1.2	12.2	72.9	0.0	3.1
Cavally		6.50					28800		3.04					4.38	-7.54	AFR	700	200	0.29	0.68	25.7	468	0	0.2	0.1	52.7	45.7	0.0	3.7
Cedar						5.78	477						7.24	47.50	-122.21	NAM				2.39	9.1	1252	0	32.5	5.2	57.2	1.1	0.0	13.6
Ceyhan (Seyhan)		23.96					20500		8.18					36.73	34.91	ASI	380	2800	7.37	2.25	9.6	341	0	1.6	0.7	13.0	35.0	0.1	3.3
Changhua		11.20					5150		9.31					19.27	108.70	ASI	232	1800	7.76	5.17	23	831	0	0.3	1.8	35.9	20.7	0.1	3.9
Changjiang	1.73	22.02	1.60	0.35	3.33	22.37	1808000	0.89	11.30	0.82	0.18	1.71	11.5	31.76	121.09	ASI	6300	3200	0.51	0.28	11.7	513	32.7	0.0	0.0	0.0	34.1	0.0	4.5
Chao Phrya		15.00					111400		3.74					13.57	100.58	ASI	1200	1000	0.83	3.40	28	250	0	32.0	5.0	11.4	28.5	2.2	4.9
Charles	7.24		0.67		7.92	5.83	640	4.52		0.42		4.94	3.64	42.37	-71.07	NAM				3.42	9.7	624	0	38.2	10.0	17.5	0.3	4.7	10.5
Chehalis	5.16				4.68	4.80	3351	4.17				3.78	3.88	46.96	-123.83	NAM				2.59	9.6	808	0	1.5	0.3	78.2	0.1	0.5	9.3
Chickahominy					7.46	2.82	650					2.86	1.08	37.27	-76.88	NAM				3.54	14.4	383	0	19.7	5.1	33.1	6.9	13.8	3.0
Chico	2.11	15.64					16800	0.12	0.88					-49.92	-68.56	SAM	410	1000	2.44	0.31	7.2	56	0	0.0	0.5	0.3	0.4	0.0	11.6
Chikugo	6.13		0.68		6.81		3000	7.56		0.84		8.40		33.21	130.36	ASI	143			3.60	13.9	1233	0	8.0	0.7	56.9	4.5	0.0	11.2
Cho Shui Chi							3157	7.18		1.18		8.36		23.83	120.28	ASI	190	3400	17.89	6.73	16		0	3.7	1.6	83.4	9.2	0.8	4.1
Choctawatchee	7.64	5.32	0.45		8.10	5.32	11400	4.21	2.93	0.25		4.46	2.93	30.41	-86.10	NAM	270	180	0.67	1.06	18.7	551	100	1.1	0.2	74.7	8.6	4.1	3.4
Chubut	2.09	24.23					138000	0.02	0.18					-43.30	-65.11	SAM	850	1000	1.18	0.27	9.2	7	0	0.3	1.3	1.1	0.4	0.0	4.5
Churchill (Atl)	5.24	0.81	0.39		5.62	0.81	92500	2.83	0.44	0.21		3.04	0.44	53.30	-60.21	NAM	560	550	0.98	0.05	-3.9	541	2.3	0.0	15.9	65.8	0.0	3.2	10.6
Churchill (Hud)	11.23	12.10	0.44		11.67		298000	3.21	3.46	0.13		3.34		58.69	-94.19	NAM	1600	200	0.13	0.09	-2.4	286	3.7	0.0	15.8	67.5	1.4	2.2	15.7
Cimanuk		15.90					3700		19.12					-6.39	108.29	ASI	150	3100	20.67	4.28	23.7	1203	0	5.1	0.1	15.3	62.4	0.3	12.6
Citanduy		7.10					3600		10.45					-7.67	108.80	ASI	120	2800	23.33	5.97	25.1	1472	0	3.0	0.0	11.8	66.1	0.1	7.2
Citarum		10.20					5900		8.45					-5.94	107.00	ASI	225	3000	13.33	2.19	23.4	829	0	7.0	3.2	13.1	62.7	0.6	8.0
Clarence	22.50						22700	3.69						-29.42	153.35	OCE	340	1500	4.41	1.43	16.4	164	0	0.1	0.5	72.6	0.4	0.1	4.4
Clutha		5.90					20300		5.46					-46.34	169.81	OCE	338	1000	2.96	2.82	7.5	926	0	0.1	3.8	7.6	25.8	0.1	4.2
Colorado (Arg)	1.18	18.62					69000	0.06	0.89					-39.64	-62.48	SAM	1000	3000	3.00	0.63	11.8	48	0	0.9	0.4	0.0	0.6	0.0	1.5
Colorado (Ari)	2.97	40.40	0.33		3.67	40.32	639000	0.01	0.11	0.00		0.01	0.11	31.92	-114.96	NAM	2330	4100	1.76	0.33	10.7	3	13.4	0.7	0.4	22.6	1.2	0.1	3.0
Colorado (Tex)	3.44	38.60	1.72	6.17	6.03	44.77	107000	0.12	1.34	0.06	0.22	0.21	1.56	28.68	-95.98	NAM	1450	1200	0.83	0.09	17.6	35	42.3	0.8	0.4	6.0	10.4	0.1	4.2
Columbia	2.68	10.23	0.11	0.20	2.78	10.43	669000	0.95	3.61	0.04	0.07	0.98	3.68	46.25	-123.57	NAM	1995	4400	2.21	0.42	5.3	353	13.7	0.0	0.0	0.2	7.2	0.2	7.3
Colville		10.51					50000		3.36					70.24	-150.83	NAM	600	1000	1.67	0.81	-12	320	23.4	0.0	1.4	0.2	0.0	1.3	12.6
Comoe		3.90					78000		0.17					5.23	-3.68	AFR	1160	420	0.36	0.33	26.8	42	0	0.4	0.1	34.4	47.0	0.0	3.5
Connecticut	3.73	7.44	2.18		6.05	8.05	28164	1.88	3.75	1.10		3.05	4.06	41.34	-72.36	NAM	520	1900	3.65	0.48	6.2	504	42.9	6.4	1.7	11.6	0.6	0.1	9.9
Coosawhatchie	14.72				14.54	3.55	526	4.10				4.05	0.99	32.54	-80.86	NAM				1.22	18.2	279	18.3	1.1	0.4	83.4	10.1	13.8	3.8
Copper	5.99		0.32		6.30		63200	4.97		0.26		5.23		60.63	-144.78	NAM	460	4800	10.43	2.84	-4.9	831	4.2	0.0	1.3	23.5	0.0	4.8	6.3
Coppermine	5.70	10.80	0.30		6.00		50700	1.24	2.34	0.07		1.30		67.80	-115.10	NAM	850	200	0.24	0.51	-11	217	13.8	0.0	10.2	4.8	0.0	0.1	5.4
Corneille	4.29						559	3.63						50.30	-63.06	NAM				3.57	1.1	846	0	0.0	8.5	80.5	0.0	0.7	18.2
Cross		7.95					48000		8.11					4.94	8.22	AFR	480	2000	4.17	0.26	26.3	1021	25.0	0.3	0.6	50.4	20.1	0.2	3.6
Cunene		6.00					106500		0.38					-17.27	11.80	AFR	830	1800	2.17	0.44	20.5	64	0	0.1	0.2	34.0	18.9	0.0	2.8
Cuyuni	5.73	4.50					53900	3.56	2.80					6.39	-58.69	SAM	560	500	0.89	0.19	25.7	622	0	0.1	0.4	82.4	6.2	0.7	4.6

Dalalven		1.60					25000		0.63					60.62	17.44	EUR	520	500	0.96	0.22	2.9	394	0	1.2	4.6	71.2	3.1	12.4	17.1
Daling							23837	1.69	19.06	9.47		11.16		40.88	121.60	ASI	397	500	1.26	0.20	7.6		14.3	1.5	0.3	4.7	65.9	0.0	2.7
Daly	7.37		2.32		9.69		53000	1.11		0.35		1.46		-13.35	130.31	OCE	360	300	0.83	0.15	27	151	0	0.0	0.1	9.4	0.1	0.2	2.7
Damodar (Hoog	3.74	18.45					20000	1.87	9.23					21.90	88.07	ASI	550	600	1.09	0.05	26.1	500	0	5.3	1.4	0.4	76.5	0.0	3.5
Danube	5.50	39.90	3.40		8.90		817000	1.39	10.11	0.86		2.25		45.23	28.68	EUR	2800	4100	1.46	0.36	8.7	253	14.6	7.0	1.0	35.0	48.3	0.5	5.2
Daugava	11.38	39.21	0.60	26.4	11.98	65.62	87900	2.64	9.10	0.14	6.13	2.78	15.2	57.04	24.07	EUR	1020	220	0.22	0.19	5.1	232	4.5	0.9	3.0	52.9	28.2	2.4	9.8
Dee	5.41	3.13	0.53		5.94		1844	2.75	1.59	0.27		3.02		57.14	-2.08	EUR	110	1300	11.82	1.77	6.1	508	0	2.8	0.3	16.1	3.0	5.0	18.2
Delangersan	6.18	2.50	0.33		6.50		2008	1.23	0.50	0.06		1.29		61.67	17.25	EUR	155			5.11	3.2	199	0	1.9	5.7	79.8	4.6	0.6	15.8
Delaware	3.18	8.80	0.73		4.53	10.57	29500	1.65	4.56	0.38		2.35	5.48	39.52	-75.55	NAM	626	570	0.91	0.26	9.1	519	40.0	0.0	1.4	0.3	5.4	0.5	4.8
Deseado	7.61	50.36					14400	0.08	0.55					-47.76	-65.90	SAM	610	1000	1.64	0.19	9.5	11	0	0.2	0.4	0.0	0.0	0.0	3.7
Dnepr	4.90	30.00	0.90		5.80		504000	0.52	3.18	0.10		0.61		46.61	32.60	EUR	1350	900	0.67	0.08	7	106	1.8	2.6	1.7	22.3	63.6	0.1	9.0
Dnestr		44.70					72100		6.63					46.44	30.23	EUR	600	1000	1.67	0.20	8	148	7.1	4.3	1.3	8.7	75.6	0.3	6.9
Doce	2.65	4.56					81000	1.07	1.85					-19.60	-39.80	SAM	600	1000	1.67	0.29	21.7	405	0	1.2	0.5	5.0	89.8	0.0	5.4
Don	4.20	39.40	1.70		5.90		442000	0.20	1.85	0.08		0.28		47.15	39.50	EUR	1870	180	0.10	0.04	7.2	47	0	3.1	1.3	4.0	77.1	0.0	6.8
Dordogne	3.87	4.33	0.43				23870	2.30	2.57	0.26				45.01	-0.52	EUR	470	1700	3.62	0.14	11.1	595	33.3	2.6	0.3	37.6	19.6	0.1	6.5
Douro	2.50	28.70					95000	0.41	4.71					41.15	-8.63	EUR	925	2100	2.27	0.36	11.2	164	10.3	1.2	0.4	16.7	57.4	0.0	4.5
Drammenselva	2.76		0.15		2.90		17000	1.31		0.07		1.38		59.74	10.21	EUR	300	1900	6.33	0.37	1	476	9.1	1.3	4.9	57.8	3.8	9.5	10.3
Du Nord	3.21						1437	2.68						56.55	-76.37	NAM				0.79	-5.6	835	0	0.0	19.2	34.2	0.0	1.2	1.7
Dumai	59.83						760	39.36						1.69	101.44	ASI				6.84	27.1	658	0	9.3	2.3	20.9	57.5	5.1	37.8
Eagle (NL, Ca)							10900	3.72	0.31	0.20		3.92	0.31	53.42	-57.68	NAM	680	200	0.29	1.05	-1.9		0	0.0	4.8	84.5	0.0	0.4	12.8
Eastmain	7.54	0.60	2.92		10.46		46000	4.62	0.37	1.79		6.41		52.23	-78.37	NAM				0.07	-2.9	613	0	0.0	7.7	71.7	0.0	7.0	13.8
Ebro	3.49	26.18	1.30		4.79		84000	0.66	4.91	0.24		0.90		40.72	0.86	EUR	930	2000	2.15	6.34	14.8	188	0	2.7	5.3	30.8	24.1	0.7	3.2
Edisto	6.38		3.83		14.32	1.79	7071	2.00		1.20		4.49	0.56	32.65	-80.40	NAM	140	200	1.43	0.05	17.5	314	28.8	1.0	0.2	72.9	16.4	14.4	3.5
Eel	4.99		1.21		5.84	13.84	8063	3.90		0.94		4.56	10.8	40.62	-124.22	NAM	320	2300	7.19	4.65	10.8	781	0	0.3	0.2	78.1	0.1	0.0	6.6
Elbe	4.70	26.17	9.86		14.56		146000	0.76	4.25	1.60		2.36		53.87	8.98	EUR	1110	500	0.45	0.34	8	162	0	10.6	1.4	29.6	50.9	0.3	6.0
Ellice	7.60	0.90	0.33		7.93		17000	0.41	0.05	0.02		0.42		68.03	-103.99	NAM	290	200	0.69	0.37	-13.3	54	0	0.0	5.1	0.1	0.0	0.0	4.2
Elwha						7.17	697						13.2	48.14	-123.56	NAM				1.43	5.2	1833	0	3.7	4.8	80.8	0.3	0.7	14.6
Emån	14.51	3.91	0.76		15.27		4472	3.57	0.96	0.19		3.76		57.13	16.50	EUR	220	200	0.91	0.02	6.2	246	0	1.8	4.7	78.3	8.8	0.3	11.9
Ems	10.10	32.85	2.60		17.80		5100	3.76	12.24	0.97		6.63		53.32	7.28	EUR	371	450	1.21	1.00	8.9	373	0	12.7	0.3	7.8	61.7	1.6	12.1
Escambia	6.66	5.60	1.10		8.09	3.42	9900	4.16	3.50	0.69		5.06	2.14	30.55	-87.19	NAM	370	180	0.49	0.03	18.1	625	0	0.5	0.1	86.9	4.0	2.0	3.3
Escatawpa						0.34	1456						0.29	30.42	-88.52	NAM				3.55	18.8	847	0	1.1	1.0	77.8	2.8	3.9	3.8
Escoumins	4.51						798	2.85						48.35	-69.41	NAM				4.05	1	632	0	0.1	3.1	76.3	0.3	0.1	9.6
Essequibo	15.60	3.40					164000	16.93	3.69					6.38	-58.61	SAM	970	1400	1.44	0.19	26.3	1085	0	0.0	0.7	91.8	0.1	3.1	5.8
Etamamiou	4.29						3030	4.69						50.27	-59.97	NAM				1.30	0.3	1093	0	0.0	8.2	84.3	0.0	0.2	8.6
Eurajoki	12.21	4.15	0.52		12.74		1336	2.56	0.87	0.11		2.67		61.23	21.61	EUR				0.22	4.3	210	0	3.8	0.6	54.6	34.9	3.8	11.5
Evros	3.84	20.04	2.02		5.86		53000	3.66	19.08	1.92		5.58		40.77	26.13	EUR	630	2900	4.60	0.60	11.2	952	20.0	5.2	0.6	28.4	60.0	0.0	4.0

Filyos		5.76					13300		2.07					41.58	32.05	ASI	230	2400	10.43	3.55	9.6	360	25.0	2.2	0.1	52.3	18.1	0.0	3.9
Fitzroy East	7.45	14.87	1.15		8.60		143000	0.30	0.59	0.05		0.34		-23.51	150.80	OCE	960	970	1.01	0.21	21	40	0	0.2	0.2	23.2	0.6	0.0	3.1
Flinders		15.90					108000		0.07					-17.60	140.60	OCE	830	300	0.36	0.03	26.7	5	0	0.0	14.0	21.4	0.0	11.5	2.5
Fly	3.26	13.58	3.17		6.43		75000	6.13	25.53	5.96		12.09		-8.33	142.82	OCE	620	4000	6.45	0.49	24.1	1880	0	0.0	3.5	88.9	6.4	0.3	7.6
Fraser	3.51	10.10	0.40		3.91		228993	1.72	4.94	0.20		1.91		49.20	-122.91	NAM	1110	4000	3.60	0.35	2.1	489	7.6	0.3	0.0	0.1	0.5	0.0	6.2
Fuchun Jiang	2.02	11.70	1.83	0.74	3.85	12.44	55600	1.47	8.50	1.33	0.54	2.80	9.04	30.39	120.54	ASI	494	900	1.82	0.43	16	727	33.3	2.9	2.6	68.6	20.1	0.0	6.7
Fyrisan	15.33		0.81		16.14		2005	3.14		0.17		3.30		59.79	17.66	EUR				0.63	5.6	204	0	5.1	10.1	56.0	23.7	0.6	10.8
Gallegos	4.49	32.75	0.04		4.53		5100	1.11	8.10	0.01		1.12		-51.60	-69.03	SAM	320	500	1.56	1.13	5.7	247	20.0	0.1	0.3	12.0	2.5	0.1	9.0
Gambia	3.34	18.47	1.43		4.78		78000	0.21	1.16	0.09		0.30		13.36	-16.24	AFR	1200	1100	0.92	2.59	26.6	63	2.2	0.7	4.4	19.0	67.6	20.2	3.9
Gamtoos	8.08		29.09		37.17		34400	0.13		0.48		0.62		-33.95	25.01	AFR	640	2200	3.44	1.29	15.8	17	12.5	0.0	0.1	5.9	2.1	0.1	2.0
Ganges	3.93	23.40	3.50		7.43		1050000	1.85	10.99	1.64		3.49		24.64	88.07	ASI	2200	7000	3.18	0.45	21.6	470	4.5	1.0	1.6	15.9	51.2	0.0	3.6
Garonne	3.10	26.20	3.20		6.30		56000	1.13	9.59	1.17		2.31		45.01	-0.57	EUR	575	3400	5.91	0.66	11.2	366	31.6	3.5	0.3	26.1	47.8	0.0	5.0
Gauja	8.78	37.40	0.46		9.24		8890	2.07	8.83	0.11		2.18		57.15	24.28	EUR	438	100	0.23	0.02	5.1	236	0	1.0	0.5	60.1	23.4	2.0	9.2
Gediz		53.40	0.28				18000		5.55	0.03				38.59	26.82	ASI	350	1500	4.29	0.30	13.8	104	0	2.6	0.7	11.2	66.5	0.0	3.7
George	1.93	1.80					41700	1.37	1.27					58.43	-65.97	NAM	550	200	0.36	0.54	-5.9	707	0	0.0	9.9	19.8	0.0	1.8	8.3
Gide	9.71	1.11	0.51		10.22		3442	2.54	0.29	0.13		2.67		63.33	19.14	EUR	225	200	0.89	6.91	2.6	261	0	5.6	6.3	76.3	5.0	0.6	13.3
Gizhiga	5.46	5.91	2.49		7.95		11700	2.29	2.48	1.04		3.34		61.95	160.38	ASI	280	1500	5.36	2.17	-9.7	420	0	0.0	0.4	23.7	0.0	0.0	9.3
Glama	2.67	2.60	1.50		4.17		41200	1.29	1.26	0.72		2.01		59.21	10.95	EUR	611	2500	4.09	0.60	0.9	483	3.6	1.3	3.2	46.0	7.1	10.8	9.8
Godavari	1.34	20.15	6.74	0.81	8.08	20.96	313000	0.45	6.76	2.26	0.27	2.71	7.03	17.00	81.75	ASI	1500	1600	1.07	0.16	26.3	335	0	1.2	1.5	2.3	78.4	0.0	3.1
Godbout	5.61						1575	4.83						49.32	-67.64	NAM				0.76	-0.3	861	0	0.0	3.6	94.3	0.0	0.1	8.4
Gota	4.70	3.92	0.21		4.90		50200	1.52	1.27	0.07		1.59		57.69	11.88	EUR	720	1700	2.36	1.10	6.6	324	0	10.9	9.1	60.8	13.8	0.5	12.1
Gr Baleine	4.25	1.50	0.20		4.45		42700	2.03	0.72	0.10		2.13		55.27	-77.75	NAM	700	200	0.29	0.36	-5.2	478	0	0.0	11.2	50.8	0.0	6.4	9.2
Grey	1.88		0.58		2.46		3800	5.20		1.60		6.80		-42.44	171.20	OCE	120	1900	15.83	4.14	9.8	2763	0	0.3	1.6	67.2	16.1	0.0	5.2
Gros Mecatina	5.39						992	4.11						51.00	-59.50	NAM				3.81	0.1	763	0	0.0	9.3	70.7	0.0	1.6	7.2
Guadalupe	6.30		0.70		7.67	49.74	13400	0.99		0.11		1.21	7.85	28.45	-96.83	NAM	740	700	0.95	0.33	20	158	50.0	3.5	0.5	17.5	1.8	0.6	4.2
Gualdalquivir		45.80					55900		27.12					36.82	-6.35	EUR	680	1500	2.21	1.80	15.8	592	25.0	1.8	0.7	25.8	42.2	0.4	3.5
Guayas			6.96				51230			4.97				-2.39	-79.85	SAM	390	3000	7.69	3.18	22	714	0	0.9	1.6	32.3	13.8	1.6	10.2
Haast			28.70				1020			168				-43.84	169.03	OCE	100	3000	30.00	1.63	7.4	5853	0	0.0	0.4	49.5	7.0	0.1	5.8
Hai Ho	14.42	74.88	15.31		29.74		264000	0.49	2.55	0.52		1.01		39.00	117.71	ASI	1300	1000	0.77	0.35	9.5	34	22.8	5.0	0.6	11.2	47.1	0.0	2.6
Han	7.10	9.50	3.30		10.40		26100	2.97	3.97	1.38		4.34		37.82	126.45	ASI	510	1300	2.55	1.20	9	418	25.0	4.9	1.4	76.6	11.2	0.0	3.3
Hanjiang	1.53	5.30	0.17		1.70		30110	1.22	4.22	0.14		1.36		23.66	116.66	ASI	488	400	0.82	0.20	19.8	797	20.0	1.2	0.7	59.8	11.1	0.0	4.2
Harricana	7.72	7.90	0.67		8.39		29300	4.72	4.83	0.41		5.13		51.15	-79.78	NAM	550	200	0.36	0.29	0.1	611	0	0.1	2.3	49.0	0.6	43.0	18.6
Harsit	2.93	17.84	0.33	1.98	3.25	19.82	3280	2.84	17.30	0.32	1.92	3.15	19.2	41.01	38.85	ASI	143	1455	10.17	7.66	8.7	970	0	1.7	0.7	64.8	12.0	0.0	5.5
Hayes	66.30	21.20	3.08		69.38		198000	7.33	2.34	0.34		7.67		57.03	-92.23	NAM	480	200	0.42	0.08	-2.9	111	26.4	0.0	8.6	28.4	0.0	60.9	19.9
Helgean	17.10	4.87	0.90		18.00		4749	5.40	1.54	0.28		5.69		55.86	14.24	EUR	190	100	0.53	3.32	7.1	316	0	3.4	4.1	68.9	16.2	2.1	14.1
Helleh		216.4					10000		21.64					29.16	50.76	ASI	210	1000	4.76	3.30	20.4	100	0	1.1	0.2	0.0	5.9	0.0	2.1
Herault	2.50						2600	0.88						43.29	3.44	EUR	148			3.19	12.5	354	96.6	4.9	0.3	52.1	22.6	0.0	3.8

Herbert	4.11		1.65		5.76		10130	2.03		0.81		2.84		-18.51	146.27	OCE	340			0.77	21.6	494	0	0.0	0.1	48.1	4.9	0.2	3.7
Hillsborough	7.89		5.39		13.28	18.09	570	3.81		2.60		6.41	8.73	27.94	-82.46	NAM				1.50	22.1	483	100	17.1	0.7	39.5	4.1	23.0	10.0
Hoh						5.04	655						15.7	47.75	-124.44	NAM				2.64	7.5	3110	0	0.2	2.0	89.4	0.0	0.7	10.7
Hong		15.90					120000		16.30					20.28	106.56	ASI	1200			0.34	19.2	1025	34.5	0.4	0.7	47.5	20.7	0.0	4.6
Housatonic	3.77				3.77	16.76	3999	2.81				2.81	12.5	41.20	-73.11	NAM				0.71	8.9	745	33.3	23.1	3.0	5.5	0.5	0.5	8.1
Hsiukuluan	0.90						1800	2.10						23.47	121.49	ASI	81	2400	29.63			2333							0.0
Huai		24.20	4.56	3.72		27.93	270000		4.48	0.84	0.69		5.17	34.10	120.30	ASI	900	1700	1.89	0.85	14.6	185	0	4.1	1.6	0.5	87.9	0.1	3.7
Hualien	0.95						1500	2.42						23.93	121.60	ASI	57	2300	40.35			2533							0.0
Huang He	1.28	28.61	8.44	114.3	9.72	142.9	752000	0.07	1.56	0.46	6.23	0.53	7.79	37.78	119.07	ASI	5465	3100	0.57	0.28	6.1	55	9.0	1.4	0.7	6.0	33.5	0.0	3.9
Hudson	3.10	12.90	0.70		3.80		34500	1.55	6.47	0.35		1.91		40.76	-74.01	NAM	490	1600	3.27	0.17	7.2	501	30.0	6.5	2.5	14.1	1.5	0.3	7.0
Hun (Daliao)							11480	0.18	1.13	0.33		0.51		40.69	122.15	ASI				0.74	7.2		11.1	8.6	1.1	51.1	33.8	0.0	4.5
Hunter	4.81						22000	0.36						-32.91	151.77	OCE	470	1200	2.55	1.00	16	75	0	2.1	0.5	48.1	0.6	0.0	3.9
Iijoki	11.08	2.26	0.58		11.67		14191	4.45	0.91	0.23		4.69		65.32	25.36	EUR	370	200	0.54	0.07	0.3	402	0	0.2	4.0	72.4	0.3	15.1	25.7
Indalsalven	3.90	4.40	0.21		4.10		26726	2.03	2.29	0.11		2.13		62.54	17.41	EUR	440	500	1.14	0.15	1.8	520	0	0.4	7.5	57.2	1.5	12.1	14.9
Indigirka	5.88	16.97	2.31		8.19		362000	0.99	2.86	0.39		1.38		70.81	148.91	ASI	1789	2000	1.12	0.43	-16.3	169	7.0	0.0	2.5	43.2	0.0	1.9	7.6
Indus	12.30	17.60	6.10		18.40		916000	0.77	1.10	0.38		1.14		25.44	68.32	ASI	3180	7800	2.45	0.59	12.5	62	6.0	0.9	0.6	5.9	30.7	0.1	2.7
Inguri		15.30					8900		2.72					42.40	41.56	ASI	210	5000	23.81	1.60	4.5	178	0	1.3	0.5	46.6	14.2	0.1	4.6
Irbe	9.50		0.50		10.00		1920	2.53		0.13		2.66		57.64	22.14	EUR	4			5.81	6.2	266	0	2.0	3.5	65.6	17.2	3.5	10.8
Irrawaddy	1.84	23.60	6.77		8.61		413710	2.16	27.72	7.95		10.11		16.92	95.59	ASI	2300	3000	1.30	0.44	21.8	1175	20.0	0.3	1.3	43.8	30.8	0.0	4.6
Ishikari	2.98	8.20	1.48		4.45		14330	3.22	8.87	1.60		4.81		43.25	141.36	ASI	268	2300	8.58	6.55	6.1	1082	19.1	0.8	1.5	9.5	3.5	0.0	6.2
Iwaki	1.63	10.19	0.67		2.30		2540	1.01	6.33	0.42		1.43		41.01	140.38	ASI	200	1000	5.00	5.02	8.8	621	0	1.6	3.2	53.5	6.3	0.2	11.8
Jacui		2.70					71500		1.55					-29.95	-51.31	SAM	450	500	1.11	0.16	18.3	573	0	1.8	0.8	20.5	53.9	0.1	5.9
James	3.21		1.76		5.64	12.49	17500	1.24		0.68		2.18	4.83	37.00	-76.49	NAM	540	1200	2.22	0.19	12.1	387	20.0	2.5	0.4	43.8	0.8	0.3	3.9
Jiulong	0.61	4.50	0.78		1.39		14700	0.61	4.50	0.78		1.39		24.45	117.89	ASI	260	790	3.04	0.70	18.9	1000	0	2.1	0.4	74.1	7.8	0.0	4.5
Jubba		22.80					750000		0.52					-0.25	42.63	AFR	1600	400	0.25	0.31	25.2	23	45.5	0.0	0.0	0.6	12.0	0.1	2.4
Jucar		47.20					21600		2.75					39.15	-0.24	EUR	506	500	0.99	0.27	13.1	58	66.7	1.1	0.3	24.1	43.5	0.0	3.5
Kalajoki	20.95	2.32	1.05		22.00		4247	6.41	0.71	0.32		6.73		64.28	23.92	EUR	140	100	0.71	6.90	2.1	306	0	1.8	2.4	70.2	16.7	4.8	20.2
Kalga	8.20						500	0.52						65.77	34.66	EUR				2.12	-0.1	63	0	0.0	14.8	72.1	0.0	8.2	14.1
Kalix	5.14	2.04	0.42		5.56		23400	2.22	0.88	0.18		2.40		65.82	23.21	EUR	450	500	1.11	0.19	-1.3	432	0	0.5	2.1	64.2	0.1	14.7	20.2
Kamchatka	7.00	9.60					55900	4.14	5.68					61.95	160.39	ASI	704	500	0.71	0.68	-3.3	592	0	0.0	0.6	52.6	0.1	13.2	18.4
Kaoping	1.36	21.60	8.52	4.16	9.88	25.76	3300	3.50	55.64	21.9	10.7	25.45	66.4	22.50	120.42	ASI	170	4000	23.53	5.84	18.3	2576	0	6.1	1.0	77.2	12.8	0.5	4.2
Kapuas	12.88	4.26	6.81		19.69		100000	13.00	4.30	6.87		19.87		-0.33	109.59	ASI		100		0.22	25.7	1009	0	0.0	1.5	53.2	41.6	1.6	7.0
Karjaanjoki	7.96	5.76	0.38		8.34		2046	2.30	1.66	0.11		2.41		60.34	25.54	EUR	850	2000	2.35	6.51		289	0	4.6	0.9	45.7	39.5	0.3	10.6
Karoon	3.86	30.72	0.60		4.46		67000	1.04	8.31	0.16		1.21		30.13	48.38	ASI	850	2000	2.35	0.63	16.8	271	55.6	0.9	1.2	0.4	25.3	0.0	2.0
Kazan	6.10	1.90	0.20		6.30		72000	1.51	0.47	0.05		1.56		64.02	-95.48	NAM				0.04	-10.5	248	0	0.0	0.0	0.0	0.0	0.5	5.5
Kelantan		4.50					13800		7.17					6.19	102.23	ASI	240	1900	7.92	1.18	24.8	1594	8.9	0.3	0.3	57.2	37.2	0.0	3.8
Kem	5.30	3.60					27700	1.57	1.06					64.96	34.67	EUR	191			0.37	0	295	0	0.1	11.6	70.9	0.1	11.5	15.5

Lestijoki	23.07	1.51	1.01		24.07		1373	5.04	0.33	0.22		5.26		64.07	23.63	EUR				4.52	2.1	218	0	1.6	0.3	66.5	15.8	10.8	19.3	.4
Letniya North	14.30	4.54					960	4.17	1.32					65.14	34.64	EUR				3.74	0.7	292	0	0.0	1.3	59.7	0.0	35.3	23.4	.3
Liao							229000	0.71	3.92	0.49	0.22	1.22	4.14	40.95	121.82	ASI	1350	1000	0.74	0.21	5.6		0	1.2	0.7	5.2	61.6	0.5	3.7	.1
Lielupe	13.14	50.60	0.69		13.83		17600	2.30	8.85	0.12		2.42		56.99	23.93	EUR	310	100	0.32	1.47	6.1	175	20.0	2.5	0.7	31.0	59.7	1.7	7.0	.0
Lijoki	10.40	1.92	0.50		10.90		14191	4.00	0.74	0.19		4.19		65.33	25.33	EUR				2.08	1.3	385	0	0.3	0.4	82.6	0.6	8.4	24.6	.0
Limpopo	0.80	28.30					440000	0.05	1.67					-25.16	33.51	AFR	1600	2000	1.25	0.20	20.7	59	31.3	1.4	0.4	25.4	32.2	0.0	2.4	.7
Ljungan	5.70	4.75	0.30		6.00		12800	1.43	1.19	0.08		1.50		62.30	17.38	EUR	360	500	1.39	0.10	2	250	0	0.5	5.1	74.9	1.1	7.3	17.0	.2
Ljungbyan	16.15	1.50	0.85		17.00		758	4.26	0.40	0.22		4.49		56.63	16.24	EUR	67			5.13	6.9	264	0	2.7	0.8	77.4	12.5	1.0	13.3	.8
Loire	4.40	23.60	2.70	0.71	7.10	24.31	112000	1.02	5.48	0.63	0.16	1.65	5.64	47.30	-2.07	EUR	1110	1900	1.71	0.31	10.5	232	42.5	4.3	0.5	18.7	43.0	0.1	5.3	.7
Lorillard	13.20	0.30	0.11		13.31		11000	3.11	0.07	0.03		3.14		64.12	-90.09	NAM		100		1.19	-13.5	236	0	0.0	2.1	0.0	0.0	0.0	4.2	.6
Los Angeles					30.14	15.90	2142					4.70	2.48	33.76	-118.20	NAM				4.21	16.5	156	0	64.5	0.1	24.9	0.1	0.0	3.3	.0
Loukkos	9.95		9.95		19.90		3750	4.18		4.18		8.37		35.20	-6.15	AFR	100			5.85	17.9	420	0	1.7	2.7	1.8	77.4	0.0	3.5	.2
Louros	1.72	34.44					952	0.59	11.75					39.05	20.77	EUR	75			5.86	14.2	341	100	2.4	5.4	22.1	44.2	0.3	2.5	.0
Luan	22.58	130.5	27.4		49.99		54000	1.76	10.15	2.13		3.89		39.45	119.23	ASI	880	2300	2.61	0.66	5.2	78	6.7	0.8	0.4	24.0	34.4	0.0	3.0	.7
Luga		24.00					12800		5.18					59.67	28.31	EUR	350	100	0.29	1.88	4.4	216	0	0.5	1.5	75.3	13.5	5.4	11.6	.8
Lulealven	2.76	2.08	0.22		2.98		24500	1.51	1.14	0.12		1.63		65.59	22.07	EUR	450	1000	2.22	0.62	-1.4	547	0	0.2	7.6	45.0	0.2	10.0	18.9	.8
Lupawa	4.01		0.45		4.45		925	1.24		0.14		1.37		54.66	17.07	EUR	99					308							0.0	.8
Lyckebyan	19.00	2.00	1.00		20.00		810	4.69	0.49	0.25		4.94		56.19	15.65	EUR				4.43	6.9	247	0	2.6	2.7	85.7	2.2	0.9	13.3	.2
Macdonald	7.59						682	5.97						50.09	-66.97	NAM				3.12	-0.8	786	0	0.0	2.8	95.3	0.0	0.0	7.9	.3
Mackenzie	6.44	21.60	5.20	5.04	11.64	26.64	1787000	1.11	3.72	0.90	0.87	2.01	4.59	67.62	-134.14	NAM	4240	3600	0.85	0.21	-4.5	172	18.6	0.0	0.0	0.2	1.8	1.2	12.6	.3
Mad						9.80	1256						10.8	40.94	-124.13	NAM				6.81	10.4	1100	0	1.8	2.5	83.0	0.0	0.3	7.2	.6
Magdalena	2.33	7.41	1.17		3.50		235000	2.35	7.47	1.18		3.53		11.05	-74.83	SAM	1530	3300	2.16	0.79	22.1	1009	6.7	1.1	2.5	30.7	15.0	1.7	17.5	.6
Magpie	3.89						7641	2.89						50.32	-64.46	NAM	240	500	2.08	0.10		743	0	0.0	7.3	61.2	0.0	0.4	10.4	.4
Mahakam		3.50					65300		4.66					-0.58	117.27	ASI	720	1700	2.36	0.20	24.9	1332	10.0	0.1	1.0	61.9	31.1	0.2	6.8	.0
Mahanadi		13.51					141600		6.30					20.46	85.75	ASI	900	440	0.49	0.24	26.2	466	4.0	0.8	1.6	3.3	77.1	0.0	3.0	.3
Maipo		19.40					15000		4.63					-33.62	-71.62	SAM	230	5600	24.35	1.10	9.7	239	0	5.6	0.3	0.1	25.2	0.1	2.8	.3
Manavgat		30.30					1300		94.86					36.74	31.48	ASI	640	1000	1.56	7.01	12.9	3131	98.6	1.4	0.8	29.6	15.3	0.0	3.4	.7
Manicouagan	4.96	0.70	0.29		5.25		45800	3.44	0.48	0.20		3.64		49.18	-68.28	NAM	560	500	0.89	0.11	-2.7	693	0	0.0	8.3	76.4	0.0	2.1	10.1	.6
Maroni	6.64	8.82					65800	5.79	7.69					5.73	-53.98	SAM	720			0.06	25.5	872	0	0.0	0.5	99.3	0.0	0.3	4.1	.3
Matamek	8.87						684	7.77						50.28	-65.97	NAM				4.32		876	0	0.0	2.9	91.6	0.0	0.5	12.8	.7
Mazaruni		3.00					14000		4.98					6.37	-58.69	SAM	560	1000	1.79	0.29	24.5	1659	0	0.0	0.7	94.9	0.3	1.7	5.7	.5
Medjerda			148.0				21800			6.45				37.11	10.19	AFR	450	1500	3.33	6.38	17.2	44	0	3.0	4.9	7.1	60.8	0.3	3.2	.2
Medway							1390	6.76	0.04	0.36		7.12	0.04	44.33	-64.93	NAM				1.20	6.2		0	0.0	7.5	47.5	0.0	0.1	12.6	.0
Mekong	3.05	12.27	3.57				795000	1.79	7.21	2.10				10.73	105.36	ASI	4350	5100	1.17	0.25	21.2	587	7.7	0.4	1.3	34.0	36.4	0.1	4.3	.3
Menjiang	3.39	3.30	3.34	1.20		4.50	61000	3.25	3.16	3.20	1.15		4.31	26.10	119.21	ASI				0.27	17.7	957	0	1.0	1.0	79.3	7.4	0.0	4.5	.9
Merikarvia	19.50	1.50	1.03		20.53		1246	9.39	0.72	0.49		9.88		61.83	21.54	EUR				0.06	3.4	482	0	1.2	2.9	73.4	10.2	7.1	16.5	.7
Mermentau							3577	4.78		0.44		5.22		29.76	-93.09	NAM				4.26	19.5	0	0	1.2	3.9	17.5	43.1	22.9	4.3	.7

Merrimack	6.29		0.75		5.96	3.02	12000	3.27		0.39		3.10	1.57	42.81	-70.87	NAM	180	1600	8.89	0.21	7	520	20.0	15.5	4.0	13.3	0.2	0.2	9.7
Meuse	4.34	32.58	0.60		4.94		34548	1.28	9.62	0.18		1.46		51.71	4.83	EUR	925			0.09	9.2	295	45.5	17.9	0.7	26.0	30.1	0.4	5.1
Mezen	11.44	54.90	1.82		13.25		78000	3.46	16.61	0.55		4.01		66.01	44.07	EUR	857	480	0.56	0.04	-0.8	303	1.5	0.0	0.5	77.9	0.0	17.2	14.9
Minho		5.50					20000		3.71					41.87	-8.86	EUR	93			2.45	11.3	675	0	2.1	0.6	54.0	21.6	0.0	8.4
Mississippi	5.10	27.10	3.20	0.23	7.73	27.33	3101692	0.99	5.26	0.62	0.04	1.50	5.30	29.93	-90.06	NAM	5985	3700	0.62	0.12	9.9	194	23.2	0.0	0.0	0.0	25.4	0.0	4.5
Mitchell		22.40					72000		3.58					-15.24	141.67	OCE	520	300	0.58	0.45	25	160	9.1	0.0	0.2	8.6	0.1	0.2	3.2
Mobile	3.64	6.50			3.35	6.48	113000	1.94	3.45			1.78	3.44	31.07	-87.97	NAM	1250	1300	1.04	0.06	16.5	531	36.0	2.2	1.1	56.2	3.2	2.2	3.8
Mogami	1.63	3.10					6400	2.87	5.47					38.91	139.83	ASI	230	2100	9.13	2.10	9.7	1766	0	2.4	0.2	36.5	7.7	0.0	9.1
Moisie	4.97	1.60	0.46		5.43		19200	4.01	1.29	0.37		4.38		50.22	-66.10	NAM	500	530	1.06	0.12	-2.9	807	0	0.0	5.2	80.8	0.0	3.0	11.0
Moose	18.72	6.96	0.80		19.52		109000	7.47	2.78	0.32		7.79		51.03	-81.00	NAM	550	320	0.58	0.08	0.8	399	3.8	0.1	1.8	78.9	0.0	12.5	17.1
Morrumsan	14.22	1.89	0.75		14.97		3369	3.80	0.50	0.20		4.00		56.15	14.75	EUR				4.59	6.4	267	0	2.4	11.8	70.7	9.2	0.8	14.3
Motagua	20.00	17.20					14000	8.51	7.32					15.74	-88.27	NAM	400	2000	5.00	0.49	21.8	426	0	0.7	0.1	38.7	6.3	0.1	7.8
Motala	7.21	10.31	0.38		7.59		15481	1.49	2.13	0.08		1.57		58.60	16.21	EUR				0.08	6	207	0	2.8	19.5	52.8	18.8	0.8	9.2
Moulouya		47.80					53500		1.41					35.12	-2.35	AFR	520	1770	3.40	0.62	14.8	30	23.1	0.2	0.1	0.1	12.1	0.0	2.3
Murray	8.10	34.75	0.90		9.00		1060000	0.06	0.26	0.01		0.07		-35.36	139.38	OCE	3490	1000	0.29	0.13	17.4	7	0.5	0.2	0.4	15.9	17.8	1.3	2.8
Musa							5000	5.23						-9.05	148.92	OCE				5.16	22.4		0	0.0	0.1	82.8	15.3	0.2	7.0
Musi		3.00					56700		4.25					-2.97	104.86	ASI	750	1700	2.27	0.71	25.7	1418	0	0.6	0.9	13.7	77.1	0.0	8.5
Musquaro	4.96						3626	3.32						50.24	-61.08	NAM				0.14	0	670	0	0.0	12.1	77.3	0.0	0.8	6.7
Myakka	9.14		10.39		19.52	6.36	593	3.88		4.41		8.29	2.70	26.96	-82.22	NAM				2.86	22.4	425	100	4.6	0.7	45.6	5.0	39.9	10.2
n Dvina	19.80	60.63	2.24		22.04		357000	6.10	18.68	0.69		6.79		64.47	40.71	EUR	744			0.04	0.8	308	13.3	0.1	0.7	87.5	0.3	7.9	11.7
Nadym	3.94	3.16	0.50		4.44		48000	1.21	0.97	0.15		1.37		66.22	71.99	ASI	250	100	0.40	1.39	-6.1	308	0	0.0	3.6	17.7	0.0	44.8	25.5
Nagavali		24.28					9400		1.95					18.22	83.93	ASI	217	1600	7.37	0.89	25.5	81	0	0.5	0.1	10.3	68.2	0.0	3.0
Nandu		7.41					7176		6.90					20.04	110.38	ASI	314	200	0.64	4.40	23.9	931	0	0.7	2.2	18.9	27.9	0.1	5.6
Napa	6.52		2.08		8.59	18.05	565	1.35		0.43		1.78	3.74	38.21	-122.31	NAM				0.22	14.5	207	0	11.8	5.0	33.5	1.0	1.0	5.5
Narmada	9.17	91.49					99000	3.61	36.04					21.66	72.76	ASI	1300	1100	0.85	0.31	25.5	394	0	0.9	1.2	2.8	84.5	0.0	3.1
Närpiönjoki	23.30	1.58	1.24		24.54		992	6.78	0.46	0.36		7.14		62.42	21.30	EUR					3.4	291	0	1.5	0.0	63.7	28.0	4.4	18.1
Narraguagus					9.83	1.15	588					7.51	0.88	44.54	-67.87	NAM				6.48	6	764	9.0	0.3	1.9	19.4	2.1	1.1	9.0
Narva	18.01	36.27	0.95		18.96		56000	3.41	6.87	0.18		3.59		59.27	27.99	EUR	77	100	1.30	2.86	4.8	189	5.7	0.8	8.3	54.5	19.7	3.2	11.1
Nastapoca	3.13						13364	1.90						56.91	-76.54	NAM	360	200	0.56	0.70	-5.9	606	0	0.0	14.8	27.1	0.0	1.2	2.2
Natashquan	5.62	0.70	0.36		5.98		16100	4.64	0.58	0.30		4.94		50.19	-61.59	NAM	320	500	1.56	0.09	-1.9	827	0	0.0	5.3	84.7	0.0	2.2	10.4
Navidad					61.42	9.12	2751					13.54	2.01	28.83	-96.58	NAM				0.06	20.3	220	0	0.2	0.9	8.7	10.4	1.6	3.9
Neches	8.66	4.10	2.25		10.87	4.92	20600	2.27	1.07	0.59		2.85	1.29	29.98	-93.87	NAM	650	150	0.23	0.03	18.7	262	0	1.3	2.7	67.4	0.2	14.5	3.6
Negro (Arg)	1.20	13.08					97000	0.36	3.98					-41.02	-62.79	SAM	1000	1000	1.00	0.41	10.7	304	3.1	0.8	2.6	4.6	1.5	0.0	3.6
Nehalem	2.76		1.07		3.83	4.29	1728	3.06		1.19		4.25	4.76	45.70	-123.89	NAM				3.17	9	1110	0	0.1	0.3	86.2	0.0	0.3	9.8
Nelson	12.17	25.40	0.44		12.62		1132000	0.96	2.00	0.03		0.99		56.95	-92.71	NAM	2600	3400	1.31	0.08	1.3	79	12.1	0.3	9.0	32.5	27.9	4.7	10.5
Nemanus	6.57	35.41	0.60		7.17		98200	1.15	6.20	0.11		1.26		55.29	21.38	EUR	937	100	0.11	0.04	6.2	175	8.7	2.1	1.6	29.8	57.7	0.7	9.7
Nestos	2.25	27.72	2.56		4.81		6100	0.38	4.68	0.43		0.81		40.85	24.80	EUR	230			1.50	8.6	169	66.7	1.8	0.7	63.6	17.0	0.0	4.4

Nethravati	0.62	35.79	3.69		4.31		3657	1.99	115.1	11.9		13.86		12.84	74.86	ASI	147			3.32	25.6	3217	0	0.4	0.3	51.7	7.7	0.0	3.7
Neuse	5.94	7.92	1.44		9.04	3.14	7000	2.12	2.83	0.52		3.23	1.12	34.99	-76.68	NAM				0.03	15.5	357	0	6.3	0.7	15.6	43.6	6.5	3.5
Neva	11.22	10.70	0.60		11.82		282000	3.20	3.05	0.17		3.37		59.95	30.34	EUR	1100	500	0.45	0.11	2.9	285	16.2	0.6	16.1	71.2	2.7	5.0	12.4
Neyyar	3.20	1.92	0.64		3.84		497	2.79	1.67	0.56		3.35		8.31	77.08	ASI	56	1844	32.93	5.31	26.6	871	0	2.9	2.4	31.9	12.6	0.0	3.7
Niger	6.27	18.67	6.81		13.08		2100000	0.46	1.37	0.50		0.96		5.32	6.44	AFR	4160	820	0.20	0.09	27.3	73	6.8	0.1	0.5	10.4	32.3	0.1	2.4
Nile	3.50	34.20	4.40	3.86	7.90	38.06	2870000	0.01	0.08	0.01	0.01	0.02	0.09	30.14	31.18	AFR	6670	3800	0.57	0.14	25.3	2	4.2	0.2	3.2	10.6	28.6	2.1	3.2
Nissan	14.55	1.88	0.77		15.31		2686	8.67	1.12	0.46		9.12		56.66	12.85	EUR				2.60	6.2	596	0	2.5	3.9	81.5	4.1	4.6	18.8
Nottaway	12.05	4.00	0.74		12.79		65800	6.87	2.28	0.42		7.29		51.26	-78.93	NAM	780	200	0.26	0.13	0	570	4.0	0.0	6.4	69.9	0.1	14.3	18.4
Nueces	11.43	39.90	2.59		6.86		40400	0.15	0.52	0.03		0.09		27.85	-97.50	NAM				0.11	20.9	13	11.1	0.2	0.4	13.0	2.6	0.1	4.8
Nykopingsan	10.13	9.17	0.53		10.67		3632	1.67	1.51	0.09		1.76		58.75	17.02	EUR				3.57		165							0.0
Nyong	10.80	3.10					19000	3.47	1.00					3.28	9.96	AFR	640	500	0.78	0.92	24.1	321	0	0.8	0.1	57.3	35.7	0.2	6.9
Ob	7.85	15.15	0.63		8.48		2990000	1.06	2.05	0.09		1.15		66.66	67.41	ASI	5400	3700	0.69	0.12	-0.7	135	3.2	0.4	2.6	43.1	18.2	17.2	13.2
Ochlockonee	14.82		0.53		15.34	2.38	2953	5.92		0.21		6.13	0.95	29.98	-84.45	NAM				0.03	19.3	400	100	0.9	1.0	73.0	19.9	20.9	3.5
Odra	8.89	27.74	2.15		11.04		119000	1.24	3.87	0.30		1.54		53.56	14.60	EUR	854	1600	1.87	0.62	8.1	139	3.9	6.9	1.3	29.4	56.8	0.2	6.7
Ogeechee	7.39				6.56	3.79	6863	3.10				2.75	1.59	31.86	-81.13	NAM				0.37	18.1	419	100	0.8	0.3	75.6	16.8	8.2	3.5
Ogooue	8.40		2.40		10.80		205000	6.15		1.76		7.91		-1.01	8.91	AFR	850	880	1.04	0.32	24.3	732	20.0	0.1	0.6	87.2	5.9	0.7	4.4
Olenek	8.26	43.43	0.67		8.93		219000	1.35	7.10	0.11		1.46		72.97	119.82	ASI	2270	500	0.22	0.64	-13.2	163	69.3	0.0	0.7	57.6	0.0	0.5	8.0
Olfusa		6.30					6200		14.12					63.93	-21.20	EUR				6.82	2	2242	0	1.1	3.7	0.3	0.1	6.1	8.4
Olomane	5.70						5439	5.39						50.24	-60.64	NAM				0.14		945	0	0.0	27.1	8.6	0.0	6.0	7.6
Omoloy	2.76	2.58	0.33		3.09		39000	0.50	0.46	0.06		0.55		71.23	132.05	ASI	1600	1500	0.94	1.07	-16.7	179	0	0.0	1.1	5.2	0.0	1.0	5.8
Onega	20.33	17.93	1.04		21.36		55700	5.62	4.96	0.29		5.91		63.92	38.04	EUR	416	200	0.48	0.72	1.5	276	89.4	0.1	2.3	80.7	0.2	13.4	15.6
Orange	4.40	21.00	52.82		57.22		1000000	0.05	0.24	0.60		0.65		-28.75	19.36	AFR	2200	3000	1.36	0.13	17.6	11	14.0	0.5	0.3	0.2	7.0	0.4	1.8
Orb	2.70						1800	1.29						43.25	3.30	EUR	145			2.43	12.9	478	99.1	8.1	0.5	62.8	16.8	0.1	4.5
Ore	11.83	1.09	0.62		12.45		3029	4.30	0.40	0.23		4.52		63.53	19.73	EUR	220	500	2.27	4.38	0.8	363	0	0.2	1.1	78.8	1.3	6.2	17.3
Orinoco	3.48	3.13	2.04		5.52		1100000	3.59	3.23	2.10		5.70		8.59	-62.25	SAM	2780	6000	2.16	0.30	25.7	1032	0	0.2	1.6	49.9	5.4	3.0	6.0
Oueme		2.20					50000		0.25					6.36	2.44	AFR	700	600	0.86	1.24	26.9	114	9.1	1.0	0.5	43.0	30.3	0.7	3.5
Oulujoki	10.28	1.96	0.50		10.78		22900	3.51	0.67	0.17		3.68		65.02	25.50	EUR	300	100	0.33	0.04	0.8	341	0	0.6	9.1	77.4	0.8	7.5	22.0
Oyapok	8.21	6.29					26900	8.64	6.62					4.20	-51.62	SAM	420	100	0.24	0.07	25.4	1052	0	0.0	0.5	99.2	0.0	0.9	3.8
Paimionjoki	10.54	7.46	0.60		11.14		1088	2.91	2.06	0.17		3.08		60.40	22.64	EUR	100	81	0.81	6.51		276	0	2.0	0.0	33.0	60.1	1.2	10.6
Palar		5.14					18000		0.51					12.48	80.13	ASI	348	500	1.44	1.49	26.6	99	0	1.1	0.7	2.7	85.1	0.0	3.0
Pamunkey	7.00	4.50	2.70		9.70		3015	2.29	1.47	0.88		3.18		37.53	-76.81	NAM				0.43	13.5	327	0	0.6	2.2	42.4	5.8	2.8	3.6
Panuco		35.00					66300		9.13					22.24	-97.83	NAM	160	2400	15.00	0.54	20.5	261	37.5	0.6	1.1	23.6	17.3	0.1	10.1
Paraiba Do Sul	2.50	6.93	0.13	0.11	2.63	7.04	57000	1.34	3.72	0.07	0.06	1.41	3.78	-21.64	-41.08	SAM	800	1800	2.25	1.85	20.1	537	0	3.7	0.5	9.1	85.1	0.0	7.2
Parana	11.42	3.33	3.09		14.50		2783000	2.33	0.68	0.63		2.96		-34.28	-58.58	SAM	4700	1000	0.21	0.14	21.6	204	1.0	1.1	1.3	26.2	44.3	5.7	4.3
Parnaiba	1.38						325000	0.14						-2.79	-41.85	SAM	1450	500	0.34	0.09	25.9	99	0	0.1	0.3	24.3	35.9	0.1	2.0
Pars?Ta	10.45		0.55		11.00		3151	3.07		0.16		3.24		54.19	15.55	EUR				6.54	7.8	294	0	2.0	0.8	42.6	44.2	0.3	6.9
Pascagoula	7.51		0.40		10.85	2.34	17100	3.87		0.20		5.60	1.21	30.42	-88.61	NAM	140	200	1.43	0.04	18	516	16.7	1.0	0.3	87.4	0.8	4.1	4.1

Patuxent	4.76		2.38		7.14	9.19	901	1.68		0.84		2.52	3.24	38.33	-76.48	NAM				1.38	12.6	353	0	18.9	0.9	16.0	7.2	1.3	3.6
Pawcatuck	7.98				7.94	1.77	764	4.82				4.80	1.07	41.33	-71.84	NAM				6.17	9.6	604	0	5.8	1.7	7.4	0.9	1.4	9.3
Pawtuxet	7.16		1.14		8.29		601	4.39		0.70		5.09		41.76	-71.39	NAM	180	100	0.56	5.26	9.5	614	0	26.6	9.0	4.9	0.1	1.7	8.8
Peace	14.25		0.68		14.93	9.57	3541	5.24		0.25		5.49	3.52	26.95	-82.05	NAM				1.71	22.4	368	94.1	6.6	4.1	24.1	11.1	14.9	8.3
Pearl	9.23	3.96	1.44		11.45	3.59	17200	4.94	2.12	0.77		6.13	1.92	30.29	-89.70	NAM	780	210	0.27	0.03	17.8	535	0	1.7	0.7	77.4	2.3	8.0	4.7
Pechora	13.88	25.52	0.30		14.18		324000	5.61	10.32	0.12		5.73		67.69	52.53	EUR	1810	680	0.38	0.45	-3.3	404	9.8	0.1	1.3	53.6	0.0	13.8	13.9
Pee Dee	5.14	4.20	0.50	0.00	6.48	4.20	23000	2.03	1.66	0.20	0.00	2.56	1.66	33.37	-79.26	NAM	570	1100	1.93	0.20	15.6	395	0	2.6	0.5	41.6	19.3	9.7	4.0
Peel	3.30	25.60	2.61	0.29	5.91	25.89	71000	1.14	8.83	0.90	0.10	2.04	8.93	67.58	-134.85	NAM				0.36	-7.9	345	33.8	0.0	0.9	25.9	0.0	4.7	3.9
Peinan	0.60						1600	1.40						22.77	121.16	ASI	84	3700	44.05			2350							0.0
Penner	8.37	36.82	0.93		9.30		55213	0.96	4.21	0.11		1.06		14.58	80.17	ASI	597	1500	2.51	0.62	27.2	114	0	0.5	0.8	1.1	87.6	0.0	3.0
Penobscot	10.47	2.80	1.76		12.23	2.26	20109	5.83	1.56	0.98		6.81	1.26	44.62	-68.85	NAM	340	1600	4.71	0.73	4.4	557	33.3	0.8	5.6	24.4	0.5	0.4	11.0
Penzhina		3.10					71600		0.99					62.47	165.32	ASI	710	2000	2.82	0.28	-10.4	318	0	0.0	0.7	6.4	0.0	0.5	8.2
Perdido	3.88		1.45		5.32	0.25	1020	3.43		1.28		4.71	0.22	30.45	-87.40	NAM				6.47	19.2	885	0	0.5	0.1	79.2	7.3	0.8	3.3
Perhonjoki	17.17	0.80	0.80		17.97		2524	5.15	0.24	0.24		5.39		63.89	23.14	EUR	130	100	0.77	1.20	2.2	300	0	1.4	2.7	71.6	9.6	10.1	22.0
Periyar	14.00		0.50		14.50		5200	33.12		1.18		34.30		9.84	76.98	ASI	550	500	0.91	1.52	23.6	2365	0	0.8	2.8	64.0	2.2	0.0	4.1
Petit Baleine	4.01						15850	1.34						56.00	-76.77	NAM	240	1800	7.50	0.07	-5.6	334	0	0.0	10.8	42.8	0.0	6.5	5.4
Petit Mecatina	4.98	0.80					19600	4.12	0.66					50.68	-59.60	NAM	380	200	0.53	0.08	-1.6	827	0	0.0	3.4	82.2	0.0	3.9	11.1
Pinios	2.62	59.28	1.54		4.16		10550	0.54	12.30	0.32		0.86		39.93	22.71	EUR	220	1900	8.64	0.18	13.9	207	0	2.9	0.1	14.0	66.4	0.0	3.0
Pitalven	3.67	1.81	0.29		3.96		11285	1.79	0.88	0.14		1.93		65.23	21.52	EUR	360			0.15	-0.8	487	15.4	0.1	5.1	59.2	0.2	14.2	19.9
Po	3.38	35.00	3.66	2.98	7.04	37.98	70000	2.36	24.45	2.56	2.08	4.92	26.5	44.95	12.31	EUR	680	4800	7.06	1.91	9.3	699	20.8	10.5	1.8	32.5	41.8	0.0	4.3
Pongoma	6.80		0.95		7.75		1220	0.88		0.12		1.00		65.35	34.41	EUR						129							0.0
Ponnaiya		41.36					16000		4.14					11.77	79.77	ASI	396	500	1.26	0.16	26	100	0	3.3	0.6	4.2	83.6	0.0	2.8
Pontax	16.49	0.25					6020	9.59	0.15					52.00	-78.69	NAM	300	100	0.33	0.08	-1.9	581	0	0.0	1.1	23.4	0.0	65.0	31.0
Porvoonjoki	12.34	8.38	0.63		12.97		1273	3.95	2.68	0.20		4.15		60.38	25.67	EUR				6.50		320	0	12.3	0.2	42.5	38.0	0.2	10.2
Potomac	3.54	14.60	2.64	3.34	6.99	17.94	30000	1.14	4.70	0.85	1.07	2.25	5.77	38.12	-76.55	NAM	660	1500	2.27	0.22	10.7	322	50.0	4.2	0.2	12.9	4.1	0.1	4.3
Povuntnituk	2.33						28000	0.99						60.04	-77.22	NAM	380	200	0.53	1.10	-8.1	425	19.0	0.0	11.4	0.1	0.0	0.0	1.4
Pregolya		52.50					15500		9.61					54.69	20.38	EUR	190	200	1.05	5.25	6.9	183	0	2.1	2.8	17.4	62.7	0.4	6.8
Progo		19.10					2500		20.05					-7.97	110.22	ASI	140	3400	24.29	5.81	23	1050	100	3.6	0.1	5.1	64.6	0.1	8.3
Pur	6.16	24.31	0.37		6.53		112000	1.99	7.86	0.12		2.11		67.45	77.71	ASI	389			0.21	-6.4	323	0	0.0	5.0	9.9	0.1	38.5	26.1
Purari		15.90					33670		39.73					-7.51	145.09	OCE	630	3700	5.87	0.88	18.6	2499	0	0.1	0.3	80.7	15.0	0.5	8.5
Puyallup	2.93		0.57		3.50	5.74	2455	2.94		0.57		3.51	5.76	47.26	-122.42	NAM				6.49	6.5	1004	0	8.5	0.6	75.1	0.1	0.3	14.3
Pyasina	4.21	7.83	1.74		5.94		125000	1.89	3.52	0.78		2.67		73.54	86.12	ASI	820	200	0.24	1.34	-12.1	450	5.9	0.0	4.7	1.0	0.0	1.0	8.0
Pyhäjoki	18.70	2.32	0.91		19.60		3712	5.16	0.64	0.25		5.41		64.45	24.28	EUR	160	100	0.63	5.85	2	276	0	1.0	4.9	75.4	9.0	4.9	20.1
Queets	1.30		2.57		3.87	3.47	1153	4.34		8.54		12.88	11.6	47.54	-124.35	NAM				3.86	7.8	3329	0	0.0	0.0	97.2	0.0	0.2	12.2
Quinault						3.98	684						13.9	47.35	-124.30	NAM				3.75	7.6	3486	0	0.0	1.3	94.4	0.0	1.0	13.7
Quoich	14.92	0.40	0.16		15.08		28700	2.76	0.07	0.03		2.79		64.07	-93.60	NAM	3	200	66.67	0.13	-14.4	185	0	0.0	6.1	0.0	0.0	0.0	4.1

Rambla Del Albujón							556	0.13						37.72	-0.86	EUR				7.62	17.5		0	9.2	4.4	11.0	33.5	0.0	2.8
Ranealven	7.48	1.50	0.39		7.87		4207	2.49	0.50	0.13		2.62		65.84	22.34	EUR				4.63	-0.1	333	0	0.9	2.8	75.6	1.1	14.3	19.0
Rangitikei							3541			1.30				-40.30	175.23	OCE	180	1000	5.56	0.33	10.3		5.7	0.4	0.3	14.3	60.5	0.0	7.6
Rappahannock	3.25		4.05		7.30	4.38	4131	1.18		1.47		2.65	1.59	37.62	-76.42	NAM				0.18	12.5	363	33.3	2.2	0.7	34.1	5.1	0.8	3.7
Raritan	3.03		0.41		3.44	9.79	1269	1.86		0.25		2.11	6.00	40.50	-74.29	NAM				0.64	10.6	613	0	39.4	0.8	11.7	3.8	0.4	4.3
Reda	13.68		0.72		14.40		485	5.43		0.29		5.71		54.61	18.33	EUR	45			6.52	6.7	397	0	11.5	3.6	27.0	50.5	0.6	7.5
Rega	9.36		1.04		10.40		2725	2.36		0.26		2.62		54.15	15.29	EUR	168	100	0.60	5.41	8.1	252	0	2.3	1.2	28.3	59.4	0.1	5.8
Rhine	5.43	31.10	3.00		8.43		224000	1.68	9.64	0.93		2.61		51.82	4.89	EUR	1360	1500	1.10	0.36	8.2	310	4.5	16.6	1.4	33.5	31.9	0.1	5.2
Rhone	2.40	35.29	3.60	1.83	6.00	37.13	95600	1.36	19.94	2.03	1.04	3.39	21.0	43.43	4.74	EUR	810	3600	4.44	0.73	8.5	565	48.5	6.9	1.2	37.5	24.6	0.2	4.2
Rianila	1.43	2.95					7800	2.36	4.86					-18.87	49.05	AFR		1510		1.05	21.6	1650	0	0.0	0.3	42.6	50.6	0.2	5.0
Ricklean	11.60	1.40	0.61		12.21		1649	3.52	0.42	0.19		3.70		64.08	20.94	EUR				6.98	1.6	303	0	0.7	3.9	83.5	3.9	4.1	19.5
Rio Grande (Us	8.46	31.40	0.64	4.85	12.08	36.25	870000	0.01	0.03	0.00	0.00	0.01	0.03	25.95	-97.15	NAM	2880	4200	1.46	0.28	16.3	1	21.1	0.7	0.3	12.0	2.1	0.0	3.7
Rioni	0.90	25.30	1.80		2.70		13400	0.87	24.36	1.73		2.60		42.20	41.67	ASI	290	2600	8.97	1.29	8	963	33.3	2.4	0.6	50.8	19.4	0.2	5.1
Roanoke	5.98	8.10	1.10		7.47	6.76	21800	1.92	2.60	0.35		2.40	2.17	35.91	-76.72	NAM	660	920	1.39	0.14	13.7	321	14.3	1.5	1.9	24.0	5.8	2.9	3.7
Rogue	2.02	9.90	0.18		2.09	6.22	10200	1.06	5.20	0.09		1.10	3.27	42.43	-124.41	NAM	340	2900	8.53	2.77	8.9	525	0	1.2	0.2	85.3	0.3	0.1	6.2
Romaine	4.33	0.60					14200	3.25	0.45					50.31	-63.73	NAM	400			0.15	-2.4	751	0	0.0	4.6	80.7	0.0	3.9	9.3
Ronnea	10.25	13.50	0.54		10.79		1996	2.05	2.71	0.11		2.16		56.27	12.84	EUR				5.78	7.6	200	0	8.2	2.7	27.8	55.9	0.4	7.1
Rufiji		9.80					178000		1.94					-7.83	39.38	AFR	1237	2900	2.34	0.25	22.5	198	0	0.0	0.5	22.3	35.9	3.9	5.4
Rupert	6.16	2.30	0.40		6.56		43000	3.97	1.48	0.26		4.22		51.49	-78.71	NAM	610	500	0.82	0.36	-1.9	644	11.8	0.0	12.6	70.6	0.0	7.9	12.1
Russian	6.29				6.29	16.66	3465	4.00				4.00	10.6	38.44	-123.11	NAM				7.28	13.3	636	0	4.9	0.6	43.4	1.8	0.1	6.2
Sabarmati		21.12					21700		3.68					22.39	72.39	ASI	420	760	1.81	0.08	26.6	174	16.7	2.3	1.0	0.2	89.2	0.0	3.3
Sabine	6.19	4.00	0.83		7.02		24200	1.57	1.01	0.21		1.78		30.00	-93.77	NAM	930	200	0.22	0.22	18.1	254	0	1.3	4.5	56.0	0.6	12.3	3.6
Saco					7.67	1.04	3349					4.77	0.65	43.47	-70.40	NAM				1.03	5.9	622	0	2.1	2.6	18.9	1.1	0.1	9.6
Sacramento	3.60	11.70	0.38		3.98		70000	1.05	3.43	0.11		1.16		38.07	-121.78	NAM	610	4300	7.05	0.50	11.3	293	0	2.4	2.4	52.8	9.0	0.1	4.9
Saguenay	6.15	2.20					88100	3.85	1.38					48.13	-69.74	NAM	700	1100	1.57	0.24	-0.3	627	0	0.2	4.9	75.4	1.2	0.8	9.3
Saint Augustin	6.00	0.70					9900	5.85	0.68					51.23	-58.66	NAM	230	450	1.96	1.40	-1	975	0	0.0	2.0	80.7	0.0	1.4	10.8
Saint John	8.88	4.30	0.47		9.35		55400	5.71	2.76	0.30		6.01		45.28	-66.09	NAM	640	760	1.19	2.44	3.6	643	4.8	0.4	2.8	28.2	4.7	0.1	13.0
Saint John's	11.24		1.37		4.46	5.10	22700	7.98		0.97		3.17	3.62	30.38	-81.63	NAM	460	100	0.22	0.43	21.2	710	83.3	8.6	7.2	57.2	3.5	17.4	6.7
Saint Lawrence	3.81	17.10	0.42	2.39	4.24	19.49	1020000	1.26	5.65	0.14	0.79	1.40	6.44	47.73	-69.83	NAM	3060	1900	0.62	0.09	5	330	19.3	2.2	26.9	31.7	12.8	2.4	5.8
Sakarya		39.30					55300		4.17					41.13	30.65	ASI	789			1.52	10.7	106	29.4	2.9	0.4	14.9	52.0	0.0	3.2
Salaca	14.79		0.78		15.57		3471	2.90		0.15		3.05		57.76	24.35	EUR	92			6.51	5.5	196	0	0.8	1.8	57.7	25.3	5.4	11.1
Salinas	10.17		1.13		16.59	13.23	10500	0.48		0.05		0.79	0.63	36.75	-121.80	NAM	280	1900	6.79	4.01	13.9	48	0	1.1	0.4	18.3	2.6	0.1	3.4
Salmon							1050	3.42	0.69	0.18		3.60	0.69	45.36	-63.37	NAM				0.82	5.5		33.3	0.7	2.8	28.7	6.2	0.1	12.3
Salween	1.07	41.70	13.66		14.73		271914	0.83	32.36	10.6		11.43		16.51	97.61	ASI	2820	2000	0.71	0.41	11.9	776	26.4	0.2	0.3	32.4	12.3	0.0	4.9
San Bernard	9.38		11.78		21.16	13.04	1883	2.39		3.00		5.39	3.32	28.87	-95.45	NAM				1.69	20.4	255	0	0.6	1.8	12.3	10.9	15.1	5.1
San Joaquin	4.68	24.40	0.52		5.20		80000	0.23	1.22	0.03		0.26		38.04	-121.71	NAM	560	4400	7.86	4.77	12.9	50	0	3.1	1.3	29.1	18.5	0.1	4.4
San Luis Rey	47.22		144.2		191.4	50.95	1443	0.76		2.32		3.08	0.82	33.20	-117.39	NAM				3.03	15.3	16	0	5.8	0.4	36.2	0.3	0.0	3.0

Sanaga	3.50	4.10	3.20		6.70		119300	1.61	1.89	1.48		3.09		3.60	9.74	AFR	860	500	0.58	0.34	23.5	461	0	0.2	1.0	71.5	12.9	0.2	4.7
Santa Ana	7.71		8.07		15.78	41.60	3859	0.43		0.45		0.88	2.32	33.63	-117.96	NAM				0.21	15.5	56	0	31.9	1.1	28.0	0.9	0.0	3.4
Santa Clara	4.92		114.6		119.6	5.14	4200	1.25		29.2		30.46	1.31	34.24	-119.26	NAM	130	2700	20.77	0.02	14	255	0	6.9	0.6	40.9	1.1	0.0	2.9
Santa Cruz	0.79	7.76					24510	0.69	6.75					-49.96	-68.60	SAM	450	500	1.11	0.90	5.5	869	0	0.1	11.2	3.0	0.7	0.0	8.9
Santee	7.56	4.20	0.84		8.40		38600	2.86	1.59	0.32		3.18		33.24	-79.49	NAM	230	1800	7.83	0.48	15.6	378	0	5.3	2.3	51.2	2.1	4.7	3.6
Sao Francisco	6.01	9.43					630000	0.86	1.35					-10.50	-36.40	SAM	3199	1400	0.44	0.16	23.3	143	28.8	0.5	1.0	11.0	50.8	0.0	3.2
Sassandra		6.70					75000		1.62					5.00	-6.12	AFR	840	500	0.60	0.09	25.3	241	0	0.3	1.0	35.0	58.0	0.1	3.6
Satilla	15.32		3.23		18.55	0.54	7226	5.36		1.13		6.49	0.19	30.97	-81.50	NAM				0.04	19.1	350	100	0.9	0.3	77.5	15.8	9.3	3.8
Savannah	5.10	4.90	0.90		6.00		25500	2.12	2.04	0.37		2.49		32.09	-81.03	NAM	505	1700	3.37	0.05	16.3	416	0	2.7	3.1	60.8	2.6	4.8	3.7
Scheldt	2.09	13.30	6.65	0.76	8.74	14.06	11400	1.10	7.00	3.50	0.40	4.60	7.40	51.37	4.23	EUR	430	100	0.23	2.58	10	526	25.0	33.8	0.4	5.1	54.0	0.2	4.5
Seal	6.65	3.70	0.35		7.00		49987	1.52	0.84	0.08		1.60		59.05	-95.02	NAM	260	200	0.77	2.06	-6.7	228	0	0.0	12.0	56.8	0.0	1.5	15.6
Sebangau	25.45		2.65		28.10		5200	69.96		7.29		77.25		-3.25	113.33	ASI	150			0.08	26	2749	0	0.0	1.0	80.6	14.9	3.5	8.2
Sebou	5.70	11.40					39000	9.21	18.42					34.27	-6.65	AFR	460	500	1.09	1.55	16.4	1615	20.0	1.5	0.5	0.4	79.7	0.0	4.2
Seine	3.65	49.60	2.58		6.23		78600	0.73	9.97	0.52		1.25		49.44	0.34	EUR	780	900	1.15	1.32	10.1	201	92.6	8.6	0.5	19.0	62.8	0.1	4.6
Senegal		5.80	1.50				441000		0.32	0.08				16.07	-16.47	AFR	1430	1200	0.84	0.20	28.1	55	7.4	0.0	0.4	1.6	30.0	0.3	2.1
Sepik	3.25	14.50	1.08	0.01	4.33	14.51	78700	4.96	22.11	1.65	0.02	6.60	22.1	-3.89	144.52	OCE	1126	2000	1.78	0.76	24.4	1525	0	0.0	1.5	81.3	15.1	1.0	8.2
Serayu		7.50	4.72				3700		10.54	6.63				-7.68	109.12	ASI	110	2800	25.45	3.04	23.7	1405	0.8	4.0	0.4	13.3	63.0	0.0	10.2
Severn (Can)	13.30		0.70				191000	1.06		0.06				55.98	-87.64	NAM	976			0.49	-2.6	80	35.3	0.0	7.0	41.0	0.0	45.5	17.1
Severn (Gb)	8.53						6800	3.24						51.66	-2.60	EUR	390	750	1.92	0.42	8.9	379	0	9.7	0.4	2.4	37.7	0.3	4.4
Shannon		92.51					11628		45.19					52.67	-8.72	EUR	368	570	1.55	0.06	9	488	100	1.5	3.8	2.8	2.0	8.9	11.9
Shatt El Arab		35.40					541300		2.99					29.98	48.49	ASI	2760	2500	0.91	0.23	17.9	85	20.4	0.8	1.6	0.4	23.3	0.0	2.3
Shinano	1.50	6.00					12200	1.95	7.82					37.66	138.79	ASI	370	1500	4.05	0.91	8.9	1303	0	3.6	0.3	57.3	5.6	0.0	12.2
Shuya	5.00	5.06	0.80		5.80		8720	0.45	0.46	0.07		0.52		64.74	34.70	EUR				3.10	0.8	90	0	0.1	1.5	61.8	0.0	30.2	22.5
Siak	24.11		4.79		28.89		11500	27.83		5.53		33.36		1.13	102.14	ASI	130	500	3.85	0.56	26.8	1154	0	0.6	0.2	18.5	74.0	9.8	17.4
Siikajoki	20.48	2.10	1.03		21.52		4218	6.35	0.65	0.32		6.67		64.84	24.74	EUR	150	100	0.67	6.94	1.8	310	0	0.6	1.1	73.2	9.1	9.5	24.8
Simojoki	13.58	2.53	0.68		14.26		3160	5.80	1.08	0.29		6.09		65.62	25.05	EUR	180	100	0.56	0.81	0.6	427	0	0.1	1.0	74.5	0.4	13.8	30.1
Sirppujoki	10.45	1.00	0.55		11.00		460	2.27	0.22	0.12		2.39		60.89	21.44	EUR				0.83	4.6	217	0	4.7	9.3	70.7	9.4	0.9	8.1
Siuslaw	3.33				3.30	2.67	1523	2.95				2.92	2.37	43.97	-124.11	NAM				0.45	10.4	886	0	0.8	0.5	87.0	0.0	0.2	9.0
Skagit	2.15	5.59	0.22		1.95	4.92	8011	3.92	10.18	0.41		3.55	8.96	48.40	-122.36	NAM	260	2800	10.77	4.81	4.5	1822	66.7	1.3	1.1	78.4	2.0	1.0	15.3
Skeena	2.11	7.30	0.14		2.25		50797	2.09	7.23	0.14		2.23		54.16	-130.03	NAM	580	2400	4.14	6.78	0.9	990	0	0.1	2.0	74.3	0.0	0.1	5.1
Skelleftalv	2.83	1.54	0.16		2.99		10500	1.05	0.57	0.06		1.11		64.71	21.15	EUR	400	100	0.25	6.69	-0.3	371	0	0.4	9.7	58.7	1.0	11.8	19.9
Skieselva	1.61	2.00	0.08		1.69		10300	1.00	1.24	0.05		1.05		59.13	9.62	EUR				0.20	1.4	621	0	1.0	6.5	49.5	2.1	4.4	8.3
Skokomish	0.89		1.06		1.95	5.72	588	1.99		2.38		4.37	12.8	47.34	-123.12	NAM				4.77	7.7	2239	0	0.0	2.6	93.5	0.4	0.6	8.7
Slupia	9.60		0.51		10.10		1623	0.75		0.04		0.79		54.59	16.85	EUR	139			1.33	7.7	78	0	3.6	4.0	40.7	43.9	0.3	5.9
Smith	1.65		1.00		2.65	11.24	1590	2.43		1.48		3.91	16.6	41.92	-124.20	NAM				3.23	9.7	1475	0	0.6	1.8	87.0	0.0	0.1	7.6
Snohomish					2.17	2.94	3981					4.38	5.94	47.94	-122.17	NAM				2.67	7	2021	0	3.3	0.6	83.7	2.9	0.2	15.2
Solo		24.00	6.13				16000		22.50	5.75				-6.92	112.58	ASI	540	1800	3.33	2.05	25.8	938	75.0	4.5	2.0	3.5	52.9	0.8	6.2

Spercheios	1.05	50.16	0.24		1.29		1158	0.16	7.80	0.04		0.20		38.86	22.57	EUR	82.5	2300	27.88	4.89	13.7	155	0	2.6	0.0	36.7	32.1	0.0	2.8
St Mary's							1350	4.19	0.18	0.22		4.41	0.18	45.07	-61.92	NAM				0.02	5.5		0	0.0	2.1	46.5	0.5	0.0	14.7
St. Marks	6.93		0.26		7.18	24.57	1386	2.96		0.11		3.07	10.5	30.12	-84.20	NAM				5.92	19.5	427	100	3.2	1.0	89.2	1.1	18.1	3.7
St. Marys	36.53				22.20	4.03	1813	17.11				10.40	1.89	30.72	-81.53	NAM				2.02	19.9	468	75.0	0.9	0.3	94.5	0.3	15.8	13.7
Steinhatchee	34.60				28.12	15.44	906	10.67				8.67	4.76	29.67	-83.40	NAM				1.38	20	308	100	0.4	0.1	96.5	0.4	45.9	6.9
Stikine	3.31	12.80	0.12		3.43		53000	3.12	12.08	0.11		3.23		56.69	-132.23	NAM	610	2900	4.75	0.79	-1.5	943	0	0.0	1.1	51.8	0.0	0.9	4.3
Strymon	2.10	36.00	1.70		3.80		16500	0.45	7.64	0.36		0.81		40.79	23.85	EUR				0.96	10.4	212	0	4.3	0.6	40.9	37.7	0.0	4.1
Suannee (Suwan	23.39	15.80	0.53		27.84		25200	8.82	5.96	0.20		10.50		29.32	-83.12	NAM						377		1.1	0.5	71.9	16.5	17.7	0.0
Subarnarekha		21.79					19300		13.96					21.57	87.34	ASI	395	500	1.27	0.55	25.9	641	0	1.5	1.3	2.1	79.9	0.0	2.9
Suriname		2.60					16000		1.79					5.88	-55.10	SAM	370	100	0.27	0.87	26.5	688	0	0.5	7.4	88.0	0.5	3.5	5.4
Susitna	2.66	12.60	0.14		2.80		50200	2.41	11.42	0.13		2.54		61.48	-150.53	NAM	504	6100	12.10	0.79	-3.7	906	0	0.0	0.7	19.3	0.0	6.5	9.5
Susquehanna	2.61	7.91	1.56		4.17		71000	1.25	3.79	0.75		2.00		42.69	-74.92	NAM	720	960	1.33	0.11	8.4	479	20.0	0.0	0.7	0.1	6.2	0.1	5.0
Swan-Avon	9.10		0.75	0.75	9.85	0.75	124000	0.06		0.01	0.01	0.07	0.01	-32.04	115.76	OCE	390	470	1.21	0.42	17.5	7	4.2	0.8	1.0	17.3	47.4	0.1	2.6
Swarna	0.72	23.28	3.96		4.68		603	2.03	65.75	11.2		13.22		13.41	74.72	ASI				6.51	26.3	2824	0	2.0	2.3	34.4	32.4	0.0	3.8
Ta Chia Chi	2.00						1200	4.32						24.33	120.57	ASI	140	2600	18.57	5.07	18.2	2163	0	15.1	1.8	60.1	14.3	0.8	4.1
Taku	1.05	6.60	0.12		1.17		17100	0.75	4.72	0.08		0.83		58.40	-134.03	NAM	266	2300	8.65	0.73	-1.2	716	27.3	0.0	1.2	55.6	0.0	3.3	2.7
Tan Shui	2.42						2700	5.33						25.16	121.44	ASI	159	3500	22.01	4.55	18.6	2200	0	14.3	1.5	78.5	3.9	0.4	4.6
Tana (Ken)	2.51	19.79	7.24		9.75		120000	0.10	0.78	0.29		0.39		-2.52	40.51	AFR	720	4000	5.56	0.37	24.5	40	0	0.1	0.2	4.0	43.0	0.6	3.3
Tapti	15.74	44.70					65000	2.35	6.67					21.14	72.72	ASI	724	750	1.04	0.43	26.4	149	0	2.2	1.3	0.4	89.0	0.0	3.1
Tar	7.04	7.80	0.99		8.03		7990	1.78	1.97	0.3		2.03		35.55	-77.08	NAM				0.04	15	253	0	2.3	0.1	17.4	36.2	5.8	3.6
Taunton	5.12		2.23		7.35		1455	3.30		1.44		4.73		41.74	-71.14	NAM				4.53	9.8	644	0	31.3	3.1	19.4	0.3	3.2	12.3
Tavignano	2.30						775	0.18						42.10	9.55	EUR	89			6.57	11.6	77	0	0.7	0.1	30.9	7.7	0.0	4.8
Taymyra	4.21	7.83	1.74		5.94		124000	1.30	2.43	0.54		1.84		75.78	99.48	ASI	640	500	0.78	1.95	-14.6	310	1.0	0.0	6.4	0.0	0.0	0.7	4.7
Taz	6.36	73.47	0.92		7.28		150000	1.66	19.20	0.24		1.90		67.51	78.69	ASI	1400	100	0.07	0.03	-6.4	261	0	0.0	2.0	37.4	0.0	21.3	15.9
Tejo		18.70					76200		2.36					38.93	-9.00	EUR	1010			0.47	13.7	126	11.1	3.1	0.8	18.5	45.6	0.0	4.1
Tenryu	4.13	8.40					4900	4.21	8.57					34.66	137.79	ASI	210	2000	9.52	2.76	9.7	1020	0	4.0	0.5	77.7	2.3	0.0	10.8
Teshio	2.60	5.40	1.09		3.69		5800	4.80	9.96	2.01		6.81		44.96	141.72	ASI	256	1500	5.86	5.31	5.1	1845	0	1.2	0.5	22.4	10.2	0.0	7.9
Tet	3.50						1400	1.00						42.71	3.04	EUR	116			2.70	12.9	286	2.8	8.7	3.3	53.3	24.6	0.7	4.7
Tevere	4.86	76.90	0.54		5.40		16500	2.17	34.40	0.24		2.42		41.78	12.28	EUR	405	2500	6.17	1.20	12.6	447	40.0	7.6	0.4	38.8	46.3	0.0	4.3
Thames	6.05	51.32	3.50		9.55		15300	1.25	10.63	0.73		1.98		51.50	0.56	EUR	350	330	0.94	2.12	9.7	207	80.0	30.5	0.7	3.8	44.8	0.6	3.6
Thelon	12.65	2.35	0.20		12.85		142000	2.26	0.42	0.04		2.29		64.28	-96.23	NAM	900	200	0.22	0.04	-10.8	179	0	0.0	14.6	8.5	0.0	0.3	4.0
Thjorsa		8.20					7200		14.35					63.82	-20.71	EUR	230	2000	8.70	6.73	4.4	1750	0	0.8	4.5	0.4	0.3	19.3	18.8
Tocantins	10.62	3.80					820000	7.35	2.63					-1.78	-49.21	SAM	2700	1100	0.41	0.10	25.6	692	4.4	0.1	1.1	17.5	42.6	3.9	4.3
Tokachi	2.88	5.30	0.50		3.38		8800	3.56	6.56	0.62		4.18		42.69	143.66	ASI	156	1500	9.62	0.95	4.6	1239	0	1.7	0.3	38.1	10.8	0.0	15.3
Tone	1.45	7.50	0.29		1.74		16800	0.71	3.70	0.14		0.86		35.74	140.82	ASI	300	2500	8.33	2.08	11.8	493	0	9.8	2.2	38.3	5.4	0.0	13.8
Tonnerre	4.20						694	4.01						50.27	-64.78	NAM				1.81		954	0	0.0	0.7	95.0	0.0	0.1	9.9
Tornionjoki	7.43	2.27	0.39		7.82		38500	2.29	0.70	0.12		2.41		65.84	24.16	EUR	510			1.09	-1.7	308	4.2	0.3	3.5	51.0	0.3	21.1	20.0

Trent	9.46	70.48	5.68		15.14		8200	2.31	17.19	1.39		3.69		53.70	-0.24	EUR	290	640	2.21	0.07	9.3	244	16.7	25.8	0.4	1.8	39.2	1.4	4.3
Trinite	5.41						562	4.55						49.41	-67.33	NAM				3.30	0.7	842	0	0.0	3.0	89.4	0.0	0.4	15.8
Trinity	8.30	14.40	1.75	27.20	12.42	41.60	48000	1.09	1.89	0.23	3.57	1.63	5.46	29.79	-94.71	NAM	960	360	0.38	0.05	18.4	131	18.2	7.4	2.9	14.2	2.3	4.2	3.7
Tsengwen	2.76						1200	5.43						23.06	120.08	ASI	148	2400	16.22	5.70	22.8	1968	0	27.2	7.1	27.1	27.0	4.3	3.9
Tugur	4.39	6.59	2.49		6.88		12000	2.31	3.47	1.31		3.62		53.76	136.78	ASI	175	1500	8.57	2.32	-4.8	526	0	0.0	0.2	79.8	0.0	0.2	18.1
Tunguda	6.60	2.52					1820	0.80	0.31					64.48	34.65	EUR				0.81	1	121	0	0.0	11.9	61.2	0.0	22.4	18.0
Tusket							1070	8.77	0.19	0.97	0.02	9.74	0.19	43.77	-65.98	NAM				6.79	6.2		0	0.3	9.7	56.2	0.4	0.5	12.4
Tyne	10.96						2935	6.83						55.01	-1.44	EUR	120	800	6.67	4.71	7.4	623	100	10.2	0.8	12.1	6.4	8.4	14.0
Uda	4.39	6.59	2.49		6.88		61300	0.20	0.30	0.11		0.31		54.68	135.20	ASI	460	1500	3.26	0.29	-7.2	45	0	0.0	0.3	90.4	0.0	0.1	13.6
Ume-Vindealven	2.93	2.49	0.15		3.09		27000	1.52	1.29	0.08		1.60		63.76	20.32	EUR	450			0.71	0	519	3.7	0.4	5.2	60.5	0.5	8.1	19.2
Umpqua	2.77		1.46		4.51	5.46	9500	1.95		1.03		3.17	3.84	43.70	-124.09	NAM	180	2800	15.56	2.47	9.5	703	0	0.6	0.3	82.6	0.0	0.0	6.7
Urugury	3.35	7.10					240000	2.02	4.29					-33.78	-58.45	SAM	1612	1000	0.62	0.16	18.7	604	0	1.0	1.1	13.6	43.0	1.8	6.3
Uskelanjoki	12.74	8.75	0.64		13.38		566	4.18	2.87	0.21		4.39		60.37	23.09	EUR				6.51		328	0	6.2	0.9	45.2	43.6	0.8	10.6
Usumacinta		27.70					47700		32.24					18.57	-92.68	NAM	430	4000	9.30	3.86	26.4	1164	0	0.1	1.6	49.1	9.3	0.5	6.6
Vamsadhara		27.14					11000		8.64					18.35	84.13	ASI	221	1000	4.52	5.71	26.4	318	0	2.3	3.6	3.5	76.3	0.0	2.9
Vantaanjoki	15.31	8.32	0.60		15.91		1686	4.64	2.52	0.18		4.82		60.22	24.98	EUR				6.43		303	0	26.0	1.1	39.7	27.3	0.4	10.8
Var	1.60						1800	1.12						43.66	7.20	EUR	114			4.22	7.7	700	50.0	2.5	0.0	51.1	22.2	0.0	5.1
Vellar		49.99					8600		4.94					11.49	79.77	ASI	193	900	4.66	0.25	27.8	99	0	0.6	0.4	6.1	81.4	0.0	2.9
Venta	9.52	48.00	0.50		10.02		8300	2.29	11.57	0.12		2.41		57.40	21.58	EUR	254	100	0.39	3.27	6.2	241	0	1.9	0.8	38.1	47.9	1.0	7.0
Ventura						17.19	487						3.31	34.28	-119.31	NAM				6.50	14.5	193	0	8.4	3.6	52.6	1.0	0.0	3.8
Vizhas							3050	3.83		0.31		4.14		66.81	45.96	EUR	219			0.03	-0.9		0	0.0	1.3	40.0	0.0	48.2	29.3
Volta	4.38	9.20					414200	0.39	0.82					5.85	0.64	AFR	1600	330	0.21	0.09	27.6	89	11.6	0.2	1.9	13.4	52.7	0.0	2.8
Waiau	1.45	7.30	8.13		9.58		7100	3.10	15.63	17.4		20.50		-42.78	173.37	OCE	180	2000	11.11	6.58	8.7	2141	0	0.1	0.2	19.9	27.1	0.0	4.7
Waikato	5.49	8.30	0.61		6.10		13700	4.85	7.33	0.54		5.39		-37.38	174.72	OCE	350	1000	2.86	2.21	12.4	883	0	1.4	5.4	27.2	58.0	0.4	14.5
Waimakariri	0.48		6.32				3200	0.57		7.50				-43.39	172.70	OCE	150	2300	15.33	1.21	8.4	1188	0	0.7	0.3	19.9	26.2	0.0	5.1
Waipaoa			118.8				2205			59.0				-38.71	177.94	OCE	80			0.54	12.7	496	0	0.2	0.3	28.6	61.8	0.0	10.7
Waitaki		5.30					6400		10.02					-44.94	171.14	OCE	150	1900	12.67	6.98	7.3	1891	0	0.0	4.4	1.4	13.4	0.0	4.7
Waitara							1122	3.20		2.90		6.10		-38.99	174.23	OCE		1000		3.31	12.6		0	0.3	0.1	30.4	60.7	0.0	18.7
Waitotara							1098			2.30				-39.85	174.69	OCE	100	500	5.00	5.51	12.4		0	0.0	0.1	64.2	25.0	0.0	14.4
Wanquan	1.80	8.82	0.15		1.95		3693	2.85	13.93	0.23		3.08		19.15	110.56	ASI	163	1200	7.36	2.97	23.9	1579	0	0.3	1.6	16.1	12.4	0.0	3.5
Warnow	14.00		2.60				3224	1.99		0.37				54.09	12.15	EUR	150			4.84	8.3	142	0	5.3	3.5	18.4	62.9	1.0	7.2
Watshishou	4.61						1052	3.59						50.28	-62.69	NAM				0.86	-0.4	779	0	0.0	8.5	90.3	0.0	0.0	8.5
Wenjiao	4.59	10.41	0.97		5.56		523	38.41	87.17	8.14		46.55		19.63	110.88	ASI	56			5.99	24.2	8375	0	1.5	6.6	1.3	55.3	0.9	5.1
Weser		33.00					45800		7.64					53.51	8.54	EUR	724	980	1.35	0.12	8.3	231	4.8	11.6	0.4	27.3	50.6	0.7	7.3
Whangaehu							1944	1.60		2.60		4.20		-40.03	175.10	OCE	110	1100	10.00	6.01	11.4		11.9	0.1	0.5	18.7	71.2	0.0	7.3
Whanganui							6785	2.40		3.80		6.20		-39.95	175.01	OCE	230	2000	8.70	3.37	11.8		0	0.5	0.1	51.2	36.3	0.0	8.9
Wieprza (Wippe	6.75		0.36		7.11		2170	0.13		0.01		0.14		54.44	16.38	EUR	112			6.50	7.8	19	0	1.3	0.6	50.2	39.3	0.0	6.6

Winisk	3.17						67300	1.20						55.24	-85.21	NAM	470	670	1.43	0.12	-2.6	379	41.4	0.0	6.5	52.1	0.0	25.7	22.2
Wisla	8.65	36.68	0.79		9.44		198000	1.42	6.02	0.13		1.55		54.33	18.94	EUR	1090			0.29	7.3	164	12.8	4.9	1.2	24.3	61.4	0.5	7.7
Withlacoochee					21.21	24.22	4727					2.46	2.81	29.05	-82.47	NAM				3.85	21.5	116	83.4	3.0	1.3	61.2	3.3	24.9	5.5
Wolf	5.68		2.51		8.19	1.30	798	3.81		1.68		5.49	0.87	30.36	-89.28	NAM				5.51	19.2	671	0	4.2	2.8	67.1	0.3	10.7	5.4
Wu Chi	1.56						2600	2.24						24.19	120.50	ASI	117	2600	22.22	3.82	19.6	1433	0	20.7	0.4	65.4	9.1	0.7	4.3
Xiaolinghe	34.05	303.1	51.06		85.10		5475	2.47	22.03	3.71		6.19		40.95	121.25	ASI	180	220	1.22	2.65	8.3	73	50.0	3.3	0.3	5.3	55.8	0.0	2.7
Yalu	2.50		2.50		5.00		61900	1.32		1.32		2.64		39.95	124.32	ASI	800	2400	3.00	0.27	3.6	529	5.0	0.9	1.3	91.1	1.7	0.0	3.7
Yana	4.51	12.42	1.18		5.69		238000	0.65	1.79	0.17		0.82		71.48	136.29	ASI	872	3000	3.44	0.39	-16.8	144	5.4	0.0	0.8	55.8	0.0	0.8	6.9
Yarra	8.44	54.61					5640	0.10	0.64					-37.84	144.90	OCE	130	1500	11.54	6.05	13	12	0	17.7	0.5	38.3	1.7	0.0	4.1
Yellow (US)					6.94	3.27	1616					4.98	2.35	30.56	-86.94	NAM				3.26	18.6	718	93.0	1.0	0.2	83.3	2.6	1.4	3.3
Yenisey	7.60	32.08	0.46		8.06		2590000	1.82	7.68	0.11		1.93		71.79	83.21	ASI	4129	3500	0.85	0.19	-5.7	239	9.8	0.2	2.5	70.7	4.7	1.7	8.5
Yesilirmak	2.32	36.48	0.26		2.57		38730	0.34	5.34	0.04		0.38		41.37	36.66	ASI	519	2600	5.01	1.28	9.3	146	10.0	1.7	0.4	16.1	40.2	0.0	3.2
Yodo	2.16	5.80	0.24		2.40		8200	2.55	6.85	0.28		2.83		34.69	135.43	ASI	75	1500	20.00	1.54	13.6	1180	50.0	11.4	9.1	45.5	5.1	0.1	7.6
Yukon	7.00	23.01	2.63	2.60	9.64	25.61	849000	1.65	5.42	0.62	0.61	2.27	6.03	62.41	-163.82	NAM	3186	6000	1.88	0.49	-6.5	236	6.6	0.0	1.5	44.6	0.0	4.0	8.7
Zaire	9.21	5.70	1.00		10.21		3698000	2.99	1.85	0.32		3.31		-6.07	12.47	AFR	4370	1100	0.25	0.11	23.7	324	4.6	0.1	1.9	60.8	24.6	4.8	4.6
Zambezi	0.38	6.30	0.66		1.04		1330000	0.03	0.50	0.05		0.08		-18.59	36.25	AFR	2660	1600	0.60	0.16	21.4	80	5.2	0.2	3.3	32.6	25.3	1.0	3.4
Zhujiang	3.13	21.06	6.98	2.77	10.11	23.82	437000	2.60	17.49	5.80	2.30	8.40	19.8	23.17	112.77	ASI	2100	2000	0.95	0.29	19.1	831	69.1	1.2	0.8	47.7	23.6	0.0	4.7

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