Reforestation – climate change and water resource implications

by Paul Egginton[1], Fred Beall[2] and Jim Buttle[3]

ABSTRACT

In a forested catchment, river discharge in any season can be either decreased or augmented by forest management practices such as appropriate species selection, density management, and length of rotation. The efficacy of any such strategy in either new plantations or existing forests can be maximized by considering the distribution of the key hydrological functions in the catchment. With the growing awareness of climate change and its impacts, the adequacy of our water supply is becoming an issue of increasing societal importance. At the same time there is greater discussion about using our forests for carbon sequestration and biofuels. Policy-makers should be careful when introducing new programs that incentivize widespread reforestation. The implications of such planting programs on annual and seasonal river flows (under both current and future climatic conditions) need to be considered. Informed choices need to be made as to the objectives for which we manage our forests. In turn, this means that there is an urgent need for water managers and forest managers to work more closely together than in the past to optimally plan and develop forest and water management strategies.

Keywords: managing river flows by managing forests; modifying seasonal river flows; managing forests for energy or water yield; problems with incenting new planting programs; forests, water, and climate change

RÉSUMÉ

Dans un basin versant forestier, le débit d'un cours d'eau peut soit augmenter, soit diminuer en fonction des pratiques d'aménagement forestier comme la sélection appropriée des espèces, l'intensité de l'aménagement et la durée de la rotation. L'efficacité d'une telle stratégie pour de nouvelles plantations ou des peuplements existants peut être maximisée par l'étude de la distribution des principales fonctions hydrologiques du bassin versant. Compte tenu de l'accroissement de la sensibilisation face aux changements climatiques et à leurs conséquences, le niveau d'approvisionnement en eau est devenu un enjeu ayant une importance sociétale croissante. Au même moment, on discute de plus en plus de l'utilisation de nos forêts pour la séquestration du carbone et la production de biocarburants. Les décideurs politiques doivent être prudents lorsque de nouveaux programmes sont introduits pour stimuler le reboisement à grande échelle. Les implications de ces programmes de reboisement sur le débit annuel des cours d'eau (en fonction des conditions climatiques actuelles et futures) doivent être étudiées. Des choix judicieux doivent être faits en fonction des objectifs pour lesquels nous aménageons nos forêts. En conséquence, cela signifie qu'il est urgent que les gestionnaires des eaux et les aménagistes forestiers collaborent plus étroitement que par le passé afin d'établir une planification optimale et de développer des stratégies adéquates d'aménagement des forêts et des eaux.

Mots clés : gestion du débit des cours d'eau par l'aménagement des forêts; modification des débits saisonniers des cours d'eau; aménager les forêts pour la production d'énergie ou pour l'apport en eau; problèmes découlant programmes incitatifs de reboisement; les forêts, l'eau et les changements climatiques

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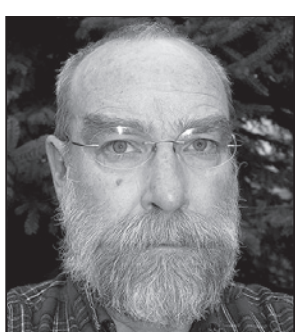

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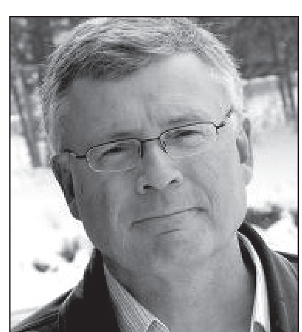

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Background

Canadians are amongst the world's largest users of water, and our natural resource sectors alone account for about 86% of this use (NRTEE 2011). In addition to this, water in our rivers, wetlands and lakes is required for a variety of objectives, such as maintenance of aquatic ecosystems, provision of adequate water levels in our lakes and rivers for boating, swimming, fishing and other recreational pursuits, as well as for the dilution of waste waters from point (e.g., sewage water treatment plants) and non-point (e.g., agricultural runoff) sources.

Many Canadians, from individual citizens to water managers, are concerned about current and future water availability. To be sure, Canada has a relative abundance of water in comparison to many other countries; nevertheless, there are some very water-poor areas in

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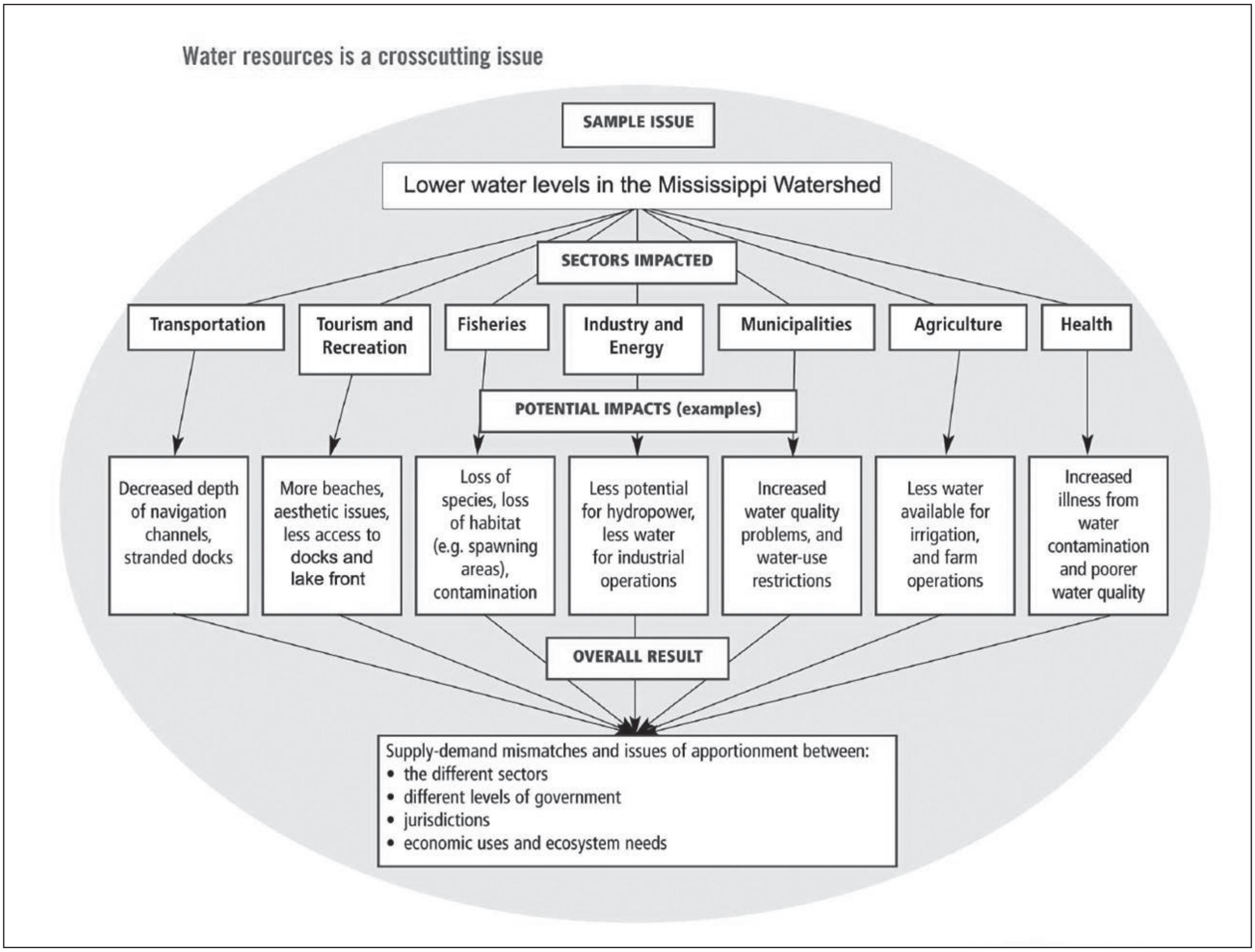

Fig. 1. An example of water resource issues in the Mississippi River catchment, eastern Ontario. Lower water levels in a catchment mean that water managers are faced with difficult decisions about priorities for water use. This is exacerbated as levels continue to drop and some sectors demand a greater share of the residual water (after Lemmen and Warren 2004). Mismatches between overall supply and demand will occur. Ecosystem services and needs are often overlooked but also must be considered.

Canada, including intermountain areas in the Cordillera, the Prairies and the Arctic, and most regions of the country experience seasonal concerns with water availability. Demand and use increase significantly during the summer months at a time when surface water levels and river flows are at yearly low levels. There are serious problems for water managers as they try to balance the varied needs and priorities of different interest groups (Fig. 1).

Trees Significantly Affect Water Quantity and Quality

We tend to take trees and forests for granted, similar to our complacency regarding water, perhaps because in most areas of Canada they are the major vegetation form that does not completely wither or become buried by snow. Trees are visible and with us throughout the winter and they are also long-lived. This may be why many people tend to view them as rather simple and passive components of our landscape. On the contrary, they are powerful biological agents that provide a very important range of ecosystem services and significantly affect the quantity, quality and timing of surface and subsurface water that is delivered from a catchment (Andréassian 2004, Jackson *et al.* 2005, Egginton *et al.* 2011, Buttle 2011a, Ford *et al.* 2011, Vose *et al.* 2011). Both the quality and stability of the water resources derived from forested landscapes are widely recognized to be unequalled by any other land use (Ice and Stednick 2004).

Reforestation Programs

There are also many good and traditional reasons for reforesting marginal lands, such as the stabilization of degraded soils, or the removal of contaminants from runoff from agricultural lands in riparian zones. There are also new and newly emerging incentives to reforestation, including carbon sequestration (McKechnie *et al* 2012), biofuel production (Mansfield *et al* 2012), and the enhancement of biodiversity in both rural and urban areas (Fraser 2010). New organizations and government programs at all levels have been and are being created that encourage planting (e.g., Trees Canada, Trees Ontario, urban forestry programs, and various provincially funded programs such as the current 50 million tree planting program in Ontario).The logical target areas for planting programs are semi-developed, but largely unused, lands around towns and cities and the so-called "marginal" lands. Typically, these are lands that have been cleared for agricultural activities that have been found to produce only marginal agricultural crops and economic returns. In many instances, returning marginal lands to a land cover closer to that of the original use is highly desirable. Indeed, these and similar more remote lands could well produce greater ecological benefits under forest cover.

For all of these reasons, the target areas for reforestation are likely to be geographically concentrated in a given catchment. Thus, the net outcome of incentivizing "new" planting programs may be to increase forest cover significantly and quickly in some sub-catchments or across entire catchments with little consideration of the hydrological implications.

Probable Consequences

If all else is held constant, the hydrological consequences of afforestation or forest restoration are: i) increased interception of precipitation; ii) reduced delivery of water to the soil surface; iii) increased transpiration from a larger leaf or needle area; and iv) reduced soil water storage and groundwater recharge. All of these changes will initially and generally lead to reductions in streamflow (annual runoff, peak and low flows), decreased groundwater recharge and changes in the timing of key hydrological events (e.g., snowmelt) in a catchment (e.g., Andréassian 2004).

Watershed Characteristics

While the generalized hydrological impacts of increasing forest cover are understood, not all catchments will respond exactly the same way to either a given reforestation program and/or the accompanying management strategies. Devito *et al.* (2005) note that the implications of forest management to surface and subsurface water in a given catchment also depend on such factors as the regional climate, surficial and bedrock geology, soil cover and catchment topography.

Of these factors, climate exerts the dominant control on a region's water resources and the amount of water that will contribute to such key processes as streamflow, surface water storage and groundwater recharge. Total annual runoff (both surface and subsurface flow) is the residual of precipitation minus actual evapotranspiration. One key issue is the proportion of the precipitation that falls as rain or snow and furthermore whether the snow remains in place until spring. Progressive accumulation of a snowpack through the winter means that a considerable fraction of annual precipitation received by a catchment may be released during the few weeks of spring melt. Spring flooding may or may not be an issue within a given catchment. Typically, most groundwater recharge occurs each year over several weeks during early spring as the snow pack melts and water is relatively slowly released. Spring melt is often accompanied by "rain on snow" events, adding to the available water on the landscape but also changing the dynamics of the melt. As a result, a steady supply of water is available for infiltration during this critical period while transpiration losses from the vegetation cover are at or near zero at this time. The microclimatic effects of forest cover on the nature of soil freezing also need to be considered. Water uptake and interception by trees tends to reduce soil water contents relative to unforested areas prior to the onset of soil freezing in the fall (Hardy *et al.* 2001). In more southerly and warmer regions of Canada, long-wave radiative fluxes from the forest cover help to reduce the depth of soil freezing compared to open sites (Shanley and Chalmers 1999). Certainly in the spring in these areas "moats" or bare spots are ubiquitous around the trunks of trees. The result is that there is a greater potential for water inputs during spring melt to infiltrate in forest soils relative to soils in agricultural areas (Greenwood and Buttle in press). Thus, any planting program that both prolongs and delays melt will likely enhance groundwater recharge and increase summer low flows to some degree (geology and climate permitting; Buttle 2011b).

Climatic controls such as the difference between annual precipitation and potential evapotranspiration provide some guidance regarding the average portion of annual precipitation that may be available for streamflow and groundwater recharge at the regional scale and the relative sensitivity of an area to regional planting programs. However, this information is of limited use when trying to assess how reforestation may affect water resources at the scale of an individual catchment. Here, factors such as bedrock and surficial geology, soil properties and topography exert a major influence on the partitioning of precipitation between such pathways as evapotranspiration, streamflow and groundwater recharge. An example of this is given in Fig. 2, which illustrates how groundwater recharge and evapotranspiration in various landscape units with the same land cover (e.g., coniferous forest) within a catchment might differ in a relative sense from regional averages. For example, evapotranspiration will likely be relatively large in areas with low-gradient slopes and either deep or shallow non-conductive soils sitting on top of non-conductive bedrock, since this would maximize the amount of water held in the soil to be evaporated or transpired. Alternatively, below-average evapotranspiration would likely occur on steep, thin-soiled, conductive slopes overlying non-conductive bedrock. Rainfall and snowmelt on these slopes would drain laterally quickly after inputs, leaving little water to be evaporated or transpired later in the summer. The suggested differences in groundwater recharge between these landscape units can be used to assess the relative contributions that groundwater may make to summer stream baseflows.

Accounting for the influence of geology, soils and topography on water storage and movement is particularly important in the context of reforestation, since many marginal lands that are often the focus of reforestation efforts are sites with shallow soils over bedrock. Fig. 2 suggests that such areas could have above- or below-average groundwater recharge depending, in part, on the relative hydraulic conductivity of soils and underlying bedrock. The increased interception and evapotranspiration that would accompany reforestation will reduce the amount of net precipitation that can contribute to soil and groundwater recharge. The result may be that landscape units that currently act as zones of slightly above-average groundwater recharge may no longer serve as recharge areas following reforestation.

Forest managers may also decide against any reforestation activity on critical recharge areas within a catchment, such as low-gradient zones of deep, conductive soils overlying permeable bedrock. The need to consider spatial context in forest management was highlighted by Creed *et al.* (2011), who emphasized the need to ensure that management strategies and reforestation programs conserve hydrological features that serve critical functions such as recharge, storage, and discharge of water along surface and subsurface pathways in the catchment (Fig. 3).

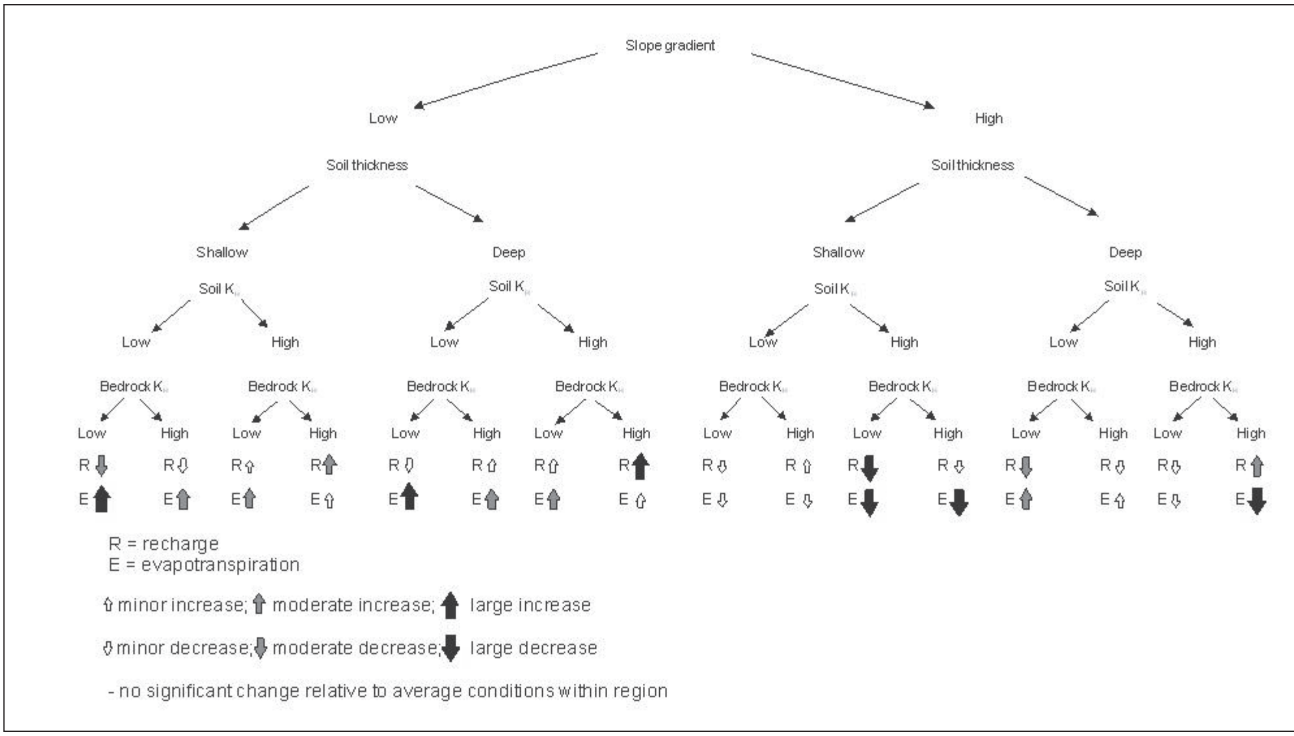

Fig. 2. Hypothesized relative differences in evapotranspiration (E) and groundwater recharge (R) between individual landscape units (defined by gradient, soil thickness, and the hydraulic conductivities (K_H) the soil and underlying bedrock) and regional average values. Arrows indicate the direction of the relative difference, and the relative magnitude of the difference is indicated by the size of the arrow.

To summarize, while climatic conditions will dictate the amount and timing of net precipitation that can contribute to streamflow, water storage and recharge at the regional scale, catchment-scale variability in such factors as topography and geology will control the location of key hydrological functions. The nature and location of these functions also need to be considered explicitly in the planting/management process.

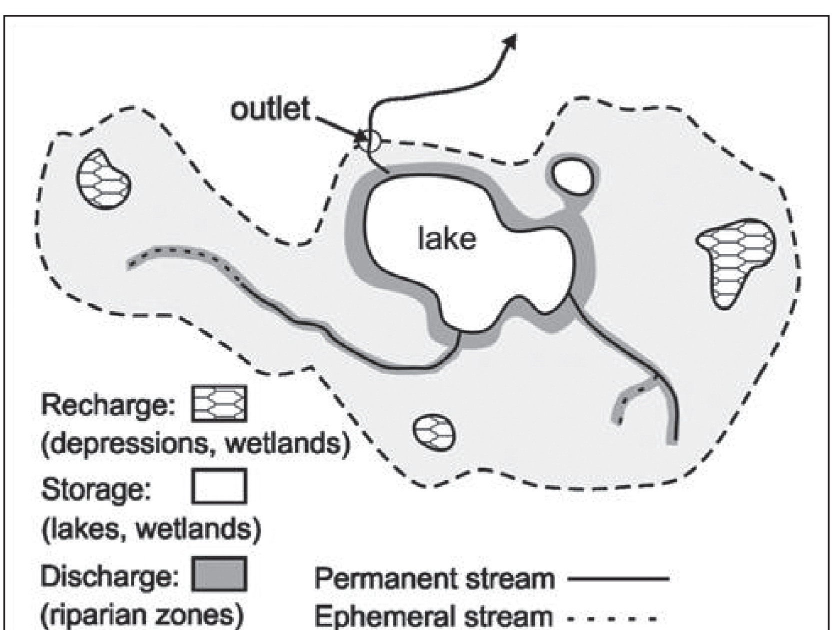

Fig. 3. Examples of areas of critical hydrologic function within a catchment (Creed *et al.* 2011).

Climate Change

Concern over future water availability in the face of climate change is a common issue for Canadians in all regions of the country. This is because Canada, which spans climates ranging from humid temperate to cold polar, will on average see about twice as much warming as the global average. In addition, precipitation and evapotranspiration rates will shift and in many areas the impact on water levels and river flows during the summer months will be negative (Lemmen *et al.* 2007).

Recent international discussions indicate that Canada and many other countries are seeking a new agreement to limit a change in in global mean temperature to 2°C above pre-industrial levels (Arora *et al.* 2011). Such an increase in global mean temperature would be associated with an average annual temperature increase in Canada of about 4°C, with even greater warming occurring in northern Canada (IPCC 2013).

The consequences of these temperature increases in Canada include shifts in the relative balance between snowfall and rainfall, and changes in total annual

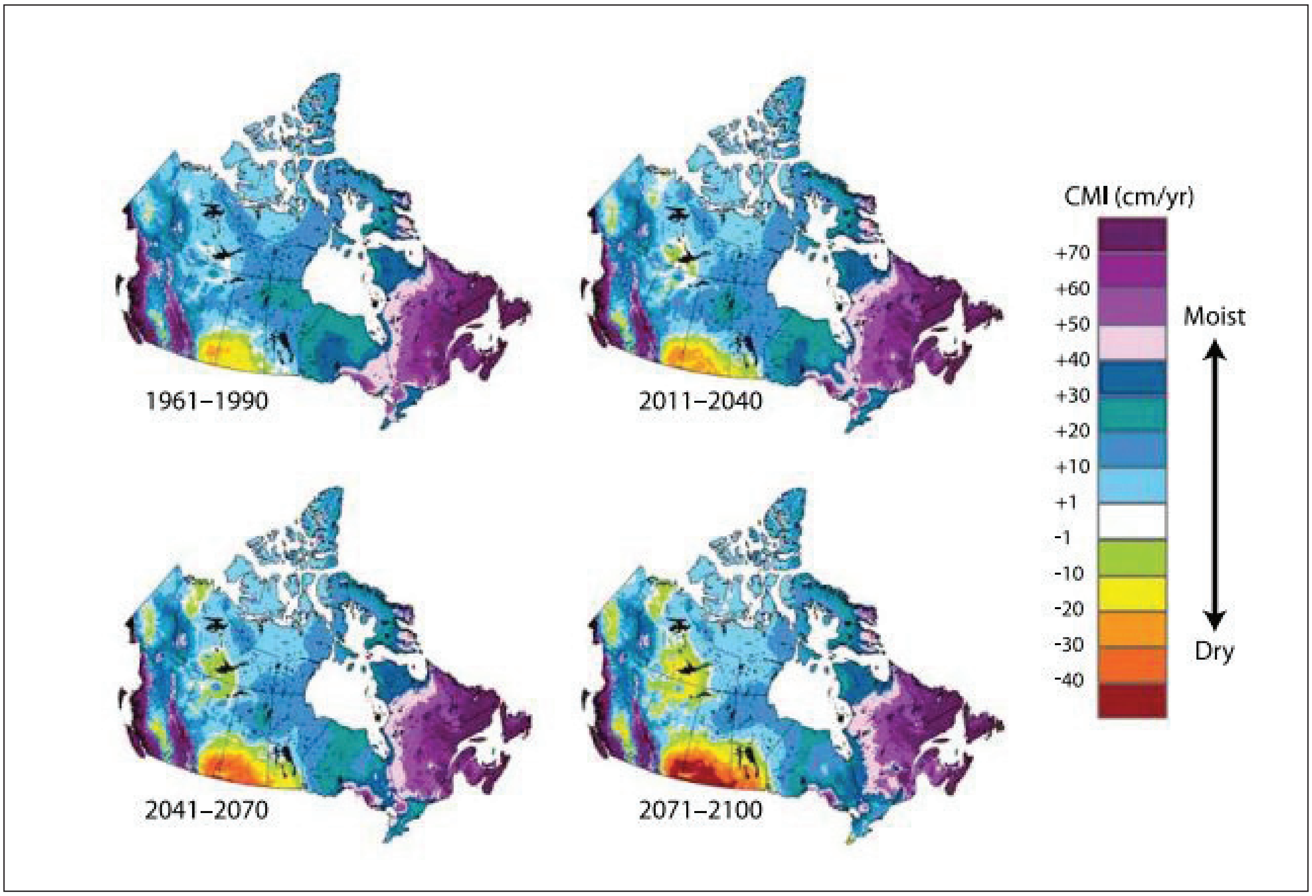

Fig. 4. Climate Moisture Index (CMI) for Canada for the baseline period (1961–1990) and for 30 year increments into the future. Maps are derived from CGCM2 model outputs using A2 scenarios, methodology after Hogg 1997 (Lemprière *et al.* 2008). CMI is calculated as the difference between annual precipitation and potential evapotranspiration.

precipitation and evapotranspiration, as well as the frequency of extreme rain and drought events (Kharin *et al.* 2007, Mladjic *et al.* 2011, Bonsal *et al.* 2012, IPCC 2013). The Climate Moisture Index (CMI) provides a rough estimate of the amount of water available for runoff in rivers and streams. It represents the residual water available after potential evaporation is subtracted from precipitation, and can be either positive or negative. Historical CMI data (1960 to 1990) along with estimates of future values are presented in Fig. 4. The historical data show that potential evaporation currently exceeds precipitation in some areas of the country such as in southern Alberta and Saskatchewan. This contrasts with eastern Canada, for example, where precipitation is greater and CMI values are positive.

Areas where potential evaporation will exceed precipitation (negative CMI values) will greatly expand in central Canada under a changing climate (Fig. 4). However, the CMI will also decrease in many other areas of the country as well. The advisability of the extensive planting of high-water-use trees in catchments where the present CMI is low and will decline in the future needs careful consideration.

Managing Forests/Plantations from the Perspective of Water Resources

Given the probable negative impacts of climate change on water resources in existing forested catchments or sub-catchments in many areas of the country, we should also consider how either new plantations or existing forests might be managed to offset these expected impacts (e.g., Vose *et al.* 2011).

There are ways to manipulate both existing forests and new plantations to increase water yield, including: i) selecting and managing for species of different water-use and interception efficiencies (e.g., coniferous versus deciduous); ii) reducing tree density to increase snow accumulation and the fraction of rainfall directly reaching the forest floor; iii) reducing the percent of the catchment that is tree-covered; iv) enhancing the functionality of recharge areas; and v) staggering various planting, harvesting and maintenance activities such that the trees in the catchment do not reach the same stage of maturity at the same time. The rationale for most of these management options is self-evident. However, the issues of transpiration rates and rotation and harvest times require further discussion.

Syntheses of study results at the global scale (e.g., Komatsu 2005) suggest greater transpiration from deciduous species relative to conifers, while a summary of daily evapotranspiration rates from US forests (Chang 2003) indicates the reverse may be true. Nevertheless, there is agreement that transpiration is highly variable between tree species (Table 1) in the same general area, between the same species in differing climates, and for the same species dependent on tree age (Komatsu 2005, Vose *et al.* 2011). For example, Hu *et al.* (2010) examined how various

Table 1. Average season daily water use from different tree species. Trees were approximately 40 cm in diameter at breast height (estimated from data from Vose et al. 2011, Fig. 5 and Ford *et al.* 2011, Fig. 11). The species composition of a forest is critical to water yield.

Species	Daily water use (kg/day)
Red oak – *Quercus rubra* L.	15
White pine[a] – *Pinus strobus* L.	15
Eastern hemlock – *Tsuga canadensis*	25
Hickory – *Carya spp.*	30
Red maple – *Acer rubrum*	45
Tulip-tree – *Liriodendron tulipifera* L.	80
Cherry birch[b] – *Betula lenta* L.	110

[a] All samples are from reference catchments at Coweeta, South Carolina, except white pine.
[b] 32 cm in diameter (DBH)

factors affect transpiration in a sub-alpine Colorado forest. They noted the key role of both temperature and tree species on transpiration at the catchment scale. Thus, transpiration from lodgepole pine for two growing seasons in the Colorado Rocky Mountains averaged 1.34 times that of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and 4.18 times that of subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.). Daily transpiration rates for all three species were significantly and positively related to air temperature and vapour pressure deficit. This illustrates for water managers the implications of both initial species selection and climate change (i.e., warmer summers) on transpiration rates from forest plantations.

Forest or plantation age also matters. Farley *et al.*'s (2005) summary of results from forest plantations from all over the world demonstrates significant decreases (40%–50%) in both annual and low flows in catchments for the first 20 to 30 years after planting. Conditions begin to ameliorate after that time due to natural processes. For example, Vertessy *et al.* (2001) examined changes in leaf area index, sapwood area index and various water balance components for different-aged mountain ash (*Eucalyptus regnans* F. Muell.) plantations in Victoria, Australia to derive estimates of changes in streamflow following harvesting of old-growth mountain ash and subsequent regrowth. Catchment annual runoff reached a minimum 15 years following harvesting (due to evapotranspiration from the mountain ash plantations that accounted for 76% of the site water balance) but runoff more than doubled 240 years following harvesting. This was attributed to a decline in sapwood and leaf area, interception and evaporation from the soil and litter layer as the ash aged Thus, significant changes in water yield and runoff can be brought about by forest management activities (Vose *et al.* 2011), such as planting species that mature at different rates, staggering the planting of a particular species so that all plantations in a catchment do not mature at the same time, and thinning plantations at different times. These practices may offer the additional benefit of augmenting biodiversity in a catchment: thus, an holistic approach is desirable.

All of the above suggest that we should be careful when introducing new programs that incentivize the widespread planting of new or different forests or plantations in a catchment. As well, we need to better understand the importance of seasonal flows to the various sectors and the ecological assets in a catchment if we are to successfully and optimally manage the water resource.

Variable Management Needs in a Catchment

It is rare that the water resource priorities in a catchment all revolve around one issue. A water manager by necessity must consider the full range of societal and ecosystem needs in determining priorities and management needs. In some catchments, land management and associated ecological issues may take priority over water management issues and objectives. Such trade-offs need to be apparent to stakeholders.

Managing low summer flows and user expectations are certainly major and widespread concerns across Canada, driven in part by human and sectoral demands and the need to protect key biological assets. However, in some sub-catchments there may be quite different seasonal water needs and priorities. For example, priorities for a water manager in one sub-catchment may be to ensure high spring flows to flush the system and to help migrating fish reach headwater lakes, and/or to ensure overbank flooding to provide water inputs to adjacent wetlands.

Forest type and management strategies can be developed that can, to greater and lesser degrees, modify flows in different seasons. In some catchments, concern regarding current or future summer high flows and resultant flooding, rather than summer low flows, may be of paramount importance. Dense forest cover and high-water-use species may be valuable in increasing interception losses during spring or summer precipitation events. In addition, species that transpire large quantities of water may be able to create significant soil moisture deficits in shallow soils supporting natural or plantation forests. These deficits may exceed the difference between soil field capacity and the wilting point, which can range from about 75 mm of water from a 1 m column of sandy loam to twice that in a silty loam (Bruce and Clark 1966). Thus, a substantial fraction of summer rainfalls would necessarily go to replenishing such deficits, resulting in less runoff to a river or stream. If rainfall intensities during the flood event exceed infiltration rates and generate overland flow, then the initial soil moisture deficit created by forests or plantations may be of limited value in reducing the potential for floods. Nevertheless, planting forests on heavily degraded soils can increase infiltration capacity and reduce overland flow and potential flooding (e.g., Greenwood and Buttle 2014). The implications of reforestation for peak flows and flooding in catchments are the subject of one of the most contentious debates in hydrology (Van Dijk *et al.* 2009). However, there appears to be a consensus that reforestation would have a greater proportional effect on small floods relative to larger ones (Buttle 2011a). Nonetheless, water managers may wish to manage forests to focus upon minimizing any flood risk and choose to ignore any potential negative impacts on current or future low summer flows: many would consider this to be a poor trade-off.

In order to highlight the range of water-related management needs within a single catchment and the potential competition between some of those needs, Table 2 provides examples of streamflow-related priorities for land managers, the hydrologic processes that drive the desired streamflow change, and the management activities that can produce the streamflow objective. It should be apparent that it will not be possible to manage for all of these needs with a given management activity,

Table 2. Suggested competing water resource outcomes associated with reforestation. Note that these outcomes only relate to the type of trees and stocking density associated with reforestation. The table is useful for considering various options; however, a more complete evaluation of the water resource outcomes associated with reforestation at a given location would need to also consider site climate, geology, soil cover, topography and the spatial variability of key hydrological functions in the catchment. C and D are coniferous and deciduous trees, respectively.

Water resource priority	Hydrologic driver	Actions
Higher spring flows	More snow on ground Rapid snow melt	Open up spacing in both D and C stands to encourage snow accumulation. Limit shading by increasing spacing between trees and by favouring D species, which provide less shading of the snowpack.
Higher summer flows	More rain reaching ground Less transpiration during growing season More ground water recharge More snow on ground Longer melt period	Open up spacing in both D and C stands to encourage snow accumulation. Favour low water use species. Choose trees with high shading potential (e.g., C species) to delay melt.
Higher fall flows	More rain reaching ground	Open up spacing in both C and D stands. Favour D species, which undergo leaf loss in Fall.
Higher winter flows	More snow reaching ground More snow melt	Open up spacing in both C and D stands to encourage snow accumulation. Favour D species, which intercept less snow and provide less shading of the snowpack.
Lower spring flows	Less snow and rain reaching ground Slower snow melt	Close spacing of D and C trees, resulting in higher interception. Favour C species, greater interception and shading.
Lower peak summer flows	Less rain reaching ground Higher soil moisture deficits leading to reduced runoff	Close spacing of D and C trees, higher interception. Favour high water use species (either C or D).
Lower peak fall flows	Less rain reaching ground Higher soil moisture deficits leading to reduced runoff	Close spacing of D and C trees, resulting in higher interception. Favour C species, they retain canopy cover during Fall.
Lower peak winter flows	Less snow or rain reaching ground Slower or limited melt	Close spacing of D and C trees, resulting in higher interception. Favour C species, more shading of snowpack and interception.

and that trade-offs will be inevitable. It also must be emphasized that while we have a good conceptual understanding of the relationships between forest attributes and hydrology, considerable further research is required to develop the data and models required to assess potential trade-offs in a quantitative manner and to develop predictive capacity in light of environmental change.

What is clear is that water managers must be able to articulate what the water management priorities are for different parts of a catchment, and to assist land managers in identifying the relevant biological assets and sectoral demands for water. This would go a long way to ensuring forests/plantations are planned and managed effectively. Integrated catchment/forestry management is more than getting as many trees into the ground in a given catchment as quickly as possible.

Forest–Water Issues Related to Reforestation – A Sense of Urgency

Climate and flow regimes are already changing in Canada, and we need to manage and/or adapt to this change; nevertheless, there are also other changes occurring in Canada's forest landscapes that require consideration, such as the desire to use forests for energy and the need to manage the impact of destructive invasive pests in our forests.

In some cases it may be possible to use waste from standard forestry activities for bioenergy; however, trucking distance (and associated emissions and costs; McKechnie *et al.* 2012) is an important and possibly over-riding issue related to any forest bioenergy project. In the future, it is likely that forest plantations, if they are established specifically for biofuels, will by necessity be geographically concentrated around processing sites and that the species used will produce significant yearly growth in the smallest area possible using hybrid poplars (Mansfield *et al.* 2012) or willows. Unfortunately, such trees are also likely to be heavy water users relative to other tree species that may be planted for more traditional uses, with associated impacts on an area's water resources. Choices between competing needs for energy, wood products, carbon sequestration, biodiversity and water in a given area will have to be made, and it is essential that these be informed by the appropriate information.

Consideration of the threat posed by the Emerald Ash Borer (*Agrilus planipennis*) or the Mountain Pine Beetle (*Dendroctonus ponderosae*) in various parts of the country is instructive. Both pests quickly decimate forests that are dominated by just a few tree species and forest loss has and will impact regional water resources. The Mountain Pine Beetle is rapidly moving eastward from BC and is now present in Alberta (Lewis and Huggard 2010, Cullingham *et al.* 2011)), while the Emerald Ash

Borer is an exotic, invasive wood-boring insect pest in North America that is causing extensive ash tree (*Fraxinus* species) mortality across an area extending from southwestern Ohio to southwestern Quebec (Cappaert *et al.* 2005). Owing to its rapid spread, the difficulties in early detection, and the scarcity of natural pathogens, predators and parasites, this invasive beetle poses a threat of nearly complete loss of ash trees from urban and rural landscapes with consequential ecological and economic impacts (Poland and McCullough 2006, Gandhi and Herms 2010, Kovacs *et al.* 2010). Forests in some catchments in southern areas of Ontario contain 80% ash, and forest managers are faced with the question of what should be replanted in a specific sub-catchment to replace infected ash stands. The priorities and needs of water managers must be clearly developed and articulated before that question can be adequately answered, at least from the perspective of managing future water resources in a given catchment. As our climate and our forests change there is a need more than ever for water managers and foresters to work closely together and to understand that their areas of expertise are both needed for successful integrated catchment management, ensuring the water resources required by society.

Conclusion

Canada as a whole has been relatively fortunate compared to other countries, because for the most part we have the water that we need. Or more precisely, we have adapted to the water supply that we have. However, as development-driven demand for water increase there will be more pronounced seasonal mismatches between supply and demand from the various sectors and biological assets in a catchment.

There is irrefutable evidence that both the global climate and the climate of Canada are changing. We are moving towards a warmer world. In Canada, apart from changes in temperature and precipitation, evapotranspiration is increasing and will continue to increase with temperature. Such changes will exacerbate current mismatches between seasonal water supply and demand in many catchments in Canada.

At the same time, we are now seeking more and different forest products from our existing forests and plantations than in the past. In some cases overall land use and the structure and management of our forests will change as we develop these products (e.g., biofuels, carbon sequestration).

Policy- and decision-makers at all levels need to understand that trees and forests are far from being the passive components of our landscape that many have thought them to be. Rather, they are powerful biological agents that alter the timing and volume and quality of water in our river systems. Thus, natural forests and forest plantations can, through species selection and forest management practices, become powerful and very useful water management tools.

There is a need for foresters, water managers, and researchers to work more closely together to develop best practices to protect our water resources. As well, there is a need for policy-makers who incentivize large reforestation programs to consider what the implications of these programs might be on a region's water resources. As in all cases involving development and change, choices will have to be made. There is no right or wrong answer; rather, it is a question of informed choice.

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