OVERVIEW OF FOREST HYDROLOGY AND FOREST MANAGEMENT EFFECTS[1]

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SUMMARY

Fundamentals of Forest Hydrology …are:

- well understood at the hydrologic process and experimental watershed level (quantity, quality, and timing are inextricably linked, etc, etc);
- more readily described than quantified at the management scale (10,000s of hectares over decades …with changing market conditions, regulatory standards, public perceptions and values, etc.);
- possible to quantify with sufficient time and commensurate resources, validated 3D models, and the willingness and ability to deal with spatial and temporal variation (uncertainty).

Forest Management Effects …on soil, water, and aquatic resources are:

- predictable in general form, magnitude, and direction (few, if any, surprises);
- more difficult to accurately predict for any given site, stand, or operating unit in any given year;
- much more difficult to accurately predict at the landscape scale over the course of decades;
- largely avoidable, or at least subject to effective mitigation, with diligent planning, supervision, and monitoring. If there's a will, there is usually a way.

Why all the fuss about water as part of Sustainable Forest Management?

- When put to the test, people care about water above all other resources. Individuals and communities rightly expect a reliable and safe drinking water supply. People also value recreational opportunities, aesthetics, and aquatic biodiversity as a metric of ecological condition.

- Forest management is "guilty until proven innocent" in the public eye (listen for keywords…lumbering, chopping down trees, etc.). Many people still "see" a black and white photo of the aftermath of circa-1900 practices when we propose and discuss 21st century SFM – the antithesis of exploitive logging.

- Water should (once again) be thought of as a primary forest product — not just a bothersome constraint on timber production, a recreational opportunity, or scenery — and managed accordingly.

National Association of State Foresters Policy Statement
The Connection between Forests and Water

> "Water, in all its uses and permutations, is by far the most valuable commodity that comes from the forest land that we manage, assist others to manage, and/or regulate."

Jackson, Mississippi, September 29, 2004

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[1] Originally prepared for a keynote presentation at the Hydro-Ecological Landscape Project workshop, University of Western Ontario, London, Ontario, Canada

Why classify landscapes and watersheds with respect to climate and geology?

- To appropriately transfer and generalize research (field and modeling) results.

- To develop a coarse filter (landscape) → fine filter (subwatershed or stand level) foundation for forest management planning, operations, and monitoring

- Because everyone else is (…or already has been) classifying, mapping, and considering other forest attributes and resources (e.g., vegetation type, site productivity, habitat characteristics and suitability, biological diversity, etc.)

- Planners, managers, policymakers, and the public ask …"How should we protect water and aquatic resources?" Saying "Err, um, like, it depends" or "it's really complicated, please come back in 10 years" will not do.

- Because we now have the science and technology to develop and apply an objective and systematic approach. A framework to organize and present our approach to the conservation and stewardship of forests *and* water is urgently needed.

Forests and Water …not exactly breaking news

1342
The first written record of a "protection forest" being established in Switzerland; there were 322 by 1777.

1897 Organic Act

"Public forest reservations are established to protect and improve the forests for the purpose of securing a permanent supply of timber for the people and insuring conditions favorable to continuous water flow."

1903 Gifford Pinchot[2], *Primer of Forestry*

“A forest, large or small, may render its service in many ways. It may reach its highest usefulness by standing as a safeguard against floods, winds, snow slides, moving sands, or especially against the dearth of water in streams.”

1954 Kenneth Davis, *American Forest Management*

"The public is vitally concerned with water and will pay a survival price to ensure adequate supply."

"Fortunately …watershed protection requirements are rather generally susceptible to harmonization with other uses."

[2] After graduating from Yale in 1888, Pinchot studied "scientific forestry" at the *Ecole Nationale des Eaux et Forets* in Nancy, France (1889-90). …of water and forests …of course

Fundamental Principles of Forest Hydrology […and Watershed Management]

1	People have been observing the link between forests and water for millennia. Urban dwellers in the 21st century are largely unaware of patterns and processes that were common knowledge for our ancestors — people who lived in close connection with the land, water, and seasons.
2	Before hydrology was recognized as a specialty or subfield of forestry, engineering, geography, and other disciplines, the study of forests, water, and climate was referred to as "forest influences." It is still a useful term and meaningful concept.
3	Forests exist where precipitation (P) > potential evapotranspiration (PET). Forests thrive where P >> PET, the growing season is long, the climate is moderate, and the frequency of natural disturbance is low (e.g., the Pacific coast). Forests are remarkably resistant to and resilient after disturbance (e.g., droughts, floods, fire, hurricanes, ice and wind damage, insects and diseases, logging, air pollution, et cetera …or typically, some combination).
4	The plant community in a forest (canopy, midstory, understory, herbaceous plants and groundcover) is dominated by deep-rooted, perennial vegetation that fully occupies the root zone (~1 to 3 meters). The biomass and density of fine roots decreases (at a non-linear rate) in relation to depth in the soil profile. In general, fine roots are concentrated in the O and A horizons in order to efficiently acquire water and nutrients for growth. Fine roots that are deeper in the soil profile can access water and nutrients when conditions near the surface are less favorable. Larger structural roots reach greater depths to anchor trees against the wind.
5 ↓	Forests soils typically have a litter layer and organic (O), mixed (A), and mineral (B and C) horizons. Forest vegetation and forest soils develop together – one influencing the other – over the course of centuries. The combination of (a) annual additions of leaf litter and woody debris, (b) root growth, (c) the actions of microbes, insects and other invertebrates, and small mammals, and (d) biogeochemical cycling lead to the development of unique soil properties relative to most other land covers and land uses. Forest soils typically have a high organic matter, porosity, and permeability (hydraulic conductivity). (Porosity represents the soil's ability to store water; permeability represents the soil's ability to transmit water.) As a result, the maximum rate of rainfall or snowmelt rarely exceeds the infiltration capacity of forest soils and overland flow (and surface erosion) is rare. A notable exception occurs when the saturated zone ("water table") reaches the surface (i.e., rain and/or snowmelt inflow exceeds available storage and the rate of outflow). The soil is the nexus for many ecological processes (energy exchange, water storage and movement, nutrient cycling, plant growth and carbon cycling at the base of the food web). Forest soils are remarkable living filters and the foundation of site productivity — they should not be treated like dirt.

5	Organic (peat) soils have two functional layers: the acrotelm (< 1 meter zone within which the water table fluctuates) and the catotelm (perennially saturated zone). The degree of decomposition and associated hydraulic properties is related to the age and depth in the profile. There is an orderly progression from young, low density (fibric) peat near the surface to old, high density (sapric) peat at the base of the deposit. Porosity and permeability vary systematically through the peat profile but rarely limit the rate of water flow. The barely measurable hydraulic gradient (‰ not %) is the principal determinant of subsurface flow rates.
6	Interception rain and snow by forest vegetation is an important hydrologic process. It may account for a substantial proportion (as much as 20 to 30%) of annual precipitation. Consider also that the forest canopy intercepts the kinetic energy of rain. Along with the protective influence of the litter layer, this ensures that the porosity and permeability of forest soils remains intact — and that soil particles are not detached and converted to sediment — long after a crust or erosion pavement forms on exposed soils (e.g., road cuts, farm fields, construction sites, etc.). One centimeter of rain on 1 hectare has a total mass of 100,000 kg (110 tons). [Comparing forests to other land covers and land uses highlights their unique functions and intrinsic ecological value.]
7 ↓	The water balance… $\mathbf{P - ET - Q \pm \Delta S \pm L = 0}$ where: P = precipitation ET = evapotranspiration Q = water yield (streamflow + groundwater recharge) S = storage (Δ signifies "change") L = leakage, in or out of the watershed …is <u>immutable</u> (based on the Law of Conservation of Mass), <u>deceptively simple</u>, *and* also remarkably powerful as a conceptual model and analytical tool. It is, or at least should be, a constant reminder of the compensatory changes in water movement and storage that are continually occurring in forest ecosystems. Natural or anthropogenic disturbance alters the water balance and initiates compensatory change(s). Neglecting the leakage term and focusing on the four primary terms (P, ET, Q, and S) yields 24 possible combinations (4 !). Expanding the definition to the primary terms into more realistic components (e.g., P = rain or snow; ET = evaporation, transpiration, and interception; Q = overland, shallow subsurface, and groundwater flow; and S is comprised of water storage in soils, wetlands, lakes, and streams) yields 1,000s of possible (and plausible) combinations. This leads to a frustrating dichotomy. Our understanding of hydrological processes and landscape patterns is well founded, while our ability to map and model the intricacies of watershed structure function and to accurately predict or forecast hydrological events is confounded by spatial and temporal variability (…the 1,000s of possible combinations of site conditions, climate, disturbance regime, and forest vegetation).

7	Could you accurately predict the streamflow response associated with 25 mm of precipitation occurring in the same forested watershed in February, April, July, October, or December? What would you need to know? Was it rain or snow …or rain-on-snow? Is it a deciduous, evergreen, or mixed forest? Is it even-aged or uneven-aged? Is there a single canopy layer or are there multiple layers? Is the forest vegetation growing or dormant? Is the soil frozen, saturated, moist, or dry? Is it a primary forest …or natural regeneration on abandoned farmland? Has it been subjected to stand-replacement fire? …insect attack? …disease outbreak? …or a combination of the above? The length of the list is directly proportional to the desired accuracy of the prediction. The cost of the prediction increases exponentially with the desired accuracy. [Are we standing too close to the proverbial picture? Should we opt for a different approach to planning, implementation …and learning and improvement? Classification and deductive reasoning?]
8	Centuries, decades, the water year, the dormant and growing seasons, days, and hours and minutes (storm events) are meaningful measures or units of time in forest hydrology and watershed management. Calendar years, months, and weeks are human constructs that artificially dampen the natural variations precipitation, evapotranspiration, streamflow, and water chemistry. The water year is a 12-month period that begins and ends at a predictably wet time of year (e.g., after fall rains or spring snowmelt). Beginning and ending the annual water balance calculation when the storage is predictably high is a mathematical device that, along with the measure of two terms, allows for the accurate estimation of the unknown term (if $\Delta S \rightarrow 0$ and L is assumed to be constant, then $P - ET \cong Q$ …or $P - Q \cong ET$).
9	Forest vegetation has an obvious influence on microclimate (air temperature, humidity, and wind speed) under the canopy; it is the "active" surface for the absorption of solar energy and carbon dioxide and the release of oxygen and water vapor. The influence of forests on regional, continental, and global climate is not as straightforward. [We know that are much better off with forests than without them. Consider the ancient civilizations that followed their life-sustaining forests and soil, in a manner of speaking, back to the sea.]
10	Riparian areas are the transition or ecotone between terrestrial and aquatic ecosystems. They can be defined in relation to landform (e.g., floodplains, channel terraces, and adjacent slopes) and their functional influence on aquatic ecosystems. Riparian forests provide a host of essential functions, including: (a) shade that influences water temperature and dissolved oxygen concentration, (b) leaf litter [carbon] inputs to microbes and invertebrates at the base of the food web, (c) structural support of stream banks, (d) large woody debris that stabilizes channels, diversifies stream habitat, and provides essential cover, and (e) hydraulic resistance to flood flows and sediment transport.

Generalized Effects of Forest Management

<table>
<tr><td>1</td><td>Roads generate overland flow and may intercept subsurface flow. As a result they are a source of stormwater and sediment. Road-stream crossings are focal points for damage (and, therefore, mitigation).</td></tr>
<tr><td>2</td><td>Timber harvesting leads to changes in water yield when the residual stand(s) cannot make use the surplus water. In other words, if the removal of trees reduces evapotranspiration and soil water depletion then increases in water yield are inevitable.

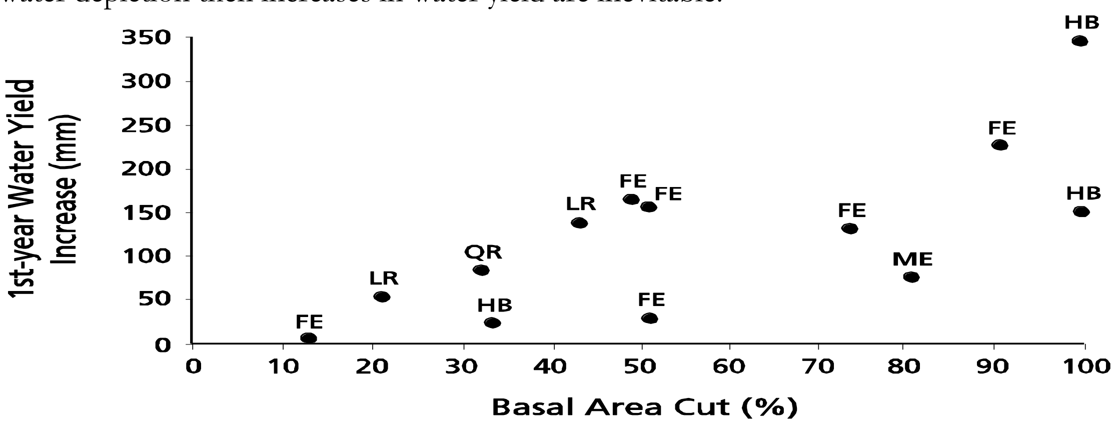

Fig. 6.6 First-year water yield increases versus cutting, FE, Fernow Experimental Forest; LR, Leading Ridge Experimental Watershed; QR, Quabbin Reservoir; ME, Marcell Experimental Forest. (Hornbeck et al., 1997b; reprinted with the permission of the National Research Council of Canada). A.L. de la Crétaz and P.K. Barten, 2007, Taylor & Francis Publishing</td></tr>
<tr><td>3</td><td>Changing forest structure, age class distribution, and/or species composition (i.e., microclimate) also can change snowmelt dynamics and associated peak discharge(s).</td></tr>
<tr><td>4</td><td>Changes in the quantity and timing of water yield typically lead to changes in water quality.</td></tr>
<tr><td>5</td><td>The recovery of hydrologic function is directly related to the regeneration of leaf area and effective rooting depth (…not height, not biomass). This can take as little as 3 to 5 growing seasons or as long as 50 or 60 years. The severity of site conditions governs the rate.</td></tr>
<tr><td>6</td><td>The legacy effects of earlier land and resource use can overshadow the effects of current use. For example, stream channels that were destabilized or burdened with sediment may continue to generate water quality and aquatic habitat problems for decades after the causal event. Soils that have been altered by erosion and a high intensity fire are less likely to foster forest regeneration — the key to an equilibrium water balance.</td></tr>
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