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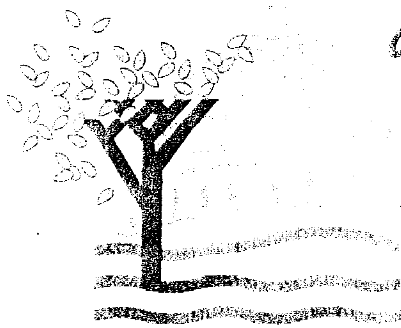

PROCEEDINGS

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LAND FRAGMENTATION AND IMPACTS TO STREAMS AND FISH IN THE CENTRAL AND UPPER MIDWEST

Elon S. Verry

ABSTRACT. Fragmentation of the land means changes in the vegetative cover. This alone has caused significant and wide spread physical and water quality changes to the streams and rivers in the central and upper Midwest. Removal of the forest canopy that changes land use to "open" conditions: agricultural, urban, or rights of way, is sufficient to initiate and prolong in-channel stream erosion and sedimentation for more than a century. The comparison between cropland and forestland, shows the loss of forest cover will cause nearly annual, bankfull, peak flows to double or triple. The processes causing higher bankfull flows are synchronized snowmelt in open land and young-aged forestland and rapid delivery of rainwater from compacted soils. In contemporary forestlands, very high rates of harvesting can also increase bankfull flows. Where forestland is not fragmented, undersized road culverts, eroding road surfaces, and road washouts, are a significant source of sediment to streams. Both high velocities in culverts, high dams, and high bankfull stream velocities have fragmented the fish, invertebrate, and mussel communities of the Midwest. This paper considers how and where these impacts occur, and suggests riparian restoration measures to bring Midwest streams to their productive best.

INTRODUCTION

Conversion of forestland to cropland (and agricultural land drainage) has caused widespread change to the physical and water quality attributes of streams in the central and upper Midwest. Permanent changes can affect stream physical condition for a century or more (Trimble 1983, Knox 1987). High rates of forest harvesting (e.g. original logging) followed by catastrophic fire can also change stream habitat over periods that exceed a century (Verry and Dolloff 2000). In addition to physical stream impacts, this paper addresses examples of fish and invertebrate community changes associated with land use change. Finally, road crossings at streams cause similar physical changes particularly in forested landscapes where road approach slopes are generally steeper than in flat agricultural landscapes.

LAND USE CHANGE

Forests covered most of the upper and central Midwest in 1620 with the exception of the tall grass prairies on its western edge. Conversion to cropland reached a peak in the late 1930s. We converted a net total of 137 million acres to agriculture and urban areas by the mid 1990s. This cycle can change stream condition because rapid runoff from open land increases the size of storm or snowmelt events that occur at frequencies of every one to two years.

The Forest Land Model

Meandering streams in the Midwest form proportional to their bankfull (or effective) discharge. These events (snowmelt or rainfall) are approximately the 1.5-year frequency flow. In the Midwest, the mixture of mature tree cover and open land presents the greatest contrast in landscape pattern that affects snowmelt (Verry, 1972; Verry et. al. 1983). Reduced water infiltration rate on compacted cropland (Knighton 1977) or forestland (Mungoven 1996) is the most probable cause of higher bankfull discharge rates in addition to higher snowmelt peaks.

Increases in flow vary with the percent and intensity of land use change within a watershed. Impacts of land use change are frequently cumulative in nature and persist over the span of centuries (Knox 1987, Fitzpatrick et al. 1999, Verry and Dolloff 2000, and Fitzpatrick and Knox in press). Examples include: original stream and river cleaning, dredging, and straightening; original logging; catastrophic fire following original logging; conversion to agriculture including: pasture, and row crops; land drainage; excessive road systems; high rates of conventional logging; and poorly constructed roads at stream crossings.

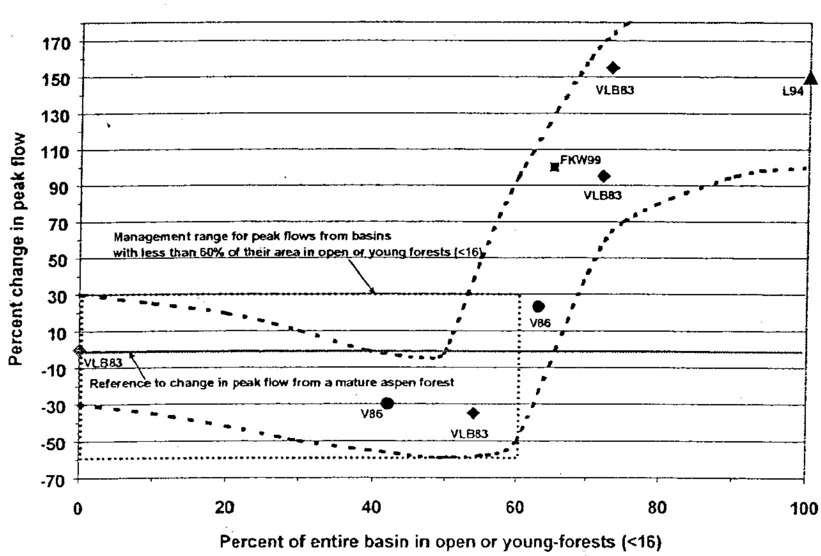

Figure 1. Response of stream flow peak discharge to percent of a basin in open land or young-forests. Dashed lines are theoretical envelope curves started at +/- 30% on the left but expanding to include all of the data to the right. Several state, county, and river basin groups use the 60% open and young forest condition to guide watershed cover condition.

Figure 1 shows a response curve incorporating both snow and rain events. The recurrence interval for these events is not always know, but a modeling study by Lu (1994) indicates they are small; ranging from the bankfull (~1.5-year event) to the 20-year event. Land use change does not increase large floods.

The Agricultural Land Model

About 65% of the upper reaches of North Fish Creek in northern Wisconsin were converted to agriculture in the 1920s with peak development in 1928. Detailed channel reconstructions and hydrologic modeling (Fitzpatrick, et al. 1999) showed the 2-year storm flow peak tripled in 1928 compared to pre conversion 1870 conditions. In 1991, after some reforestation, peak flows were double those in 1870. Predicted sediment yield for the same storm in 1928 was five times that from a similar storm in 1870 and still 2.5 times higher in 1991.

A separation of sediment sources for the 1991 storm (metric tonnes/storm) yields 1110 from upland erosion, 6300 from channel bank erosion, and 15000 from high terrace clay slumps into the channel. Peak flow rates in western Iowa increased 10 to 50 times compared with pre settlement, natural prairie rates (Priest et al. 1976, 1977), and sediment yields in Michigan and Ohio increased one or two orders of magnitude (Davis 1976, Evans et al. 2000).

Land drainage also increases peak flows. The form of the response curve for "percent of basin in a drained condition" is similar to that for the "percent of open and young-forest in the basin" (Fig. 1); however, the rapid rise in response occurs when only 30% of the basin is in a drained condition (Verry 1988).

A sequence of mechanisms leading to larger bankfull flow rates in cropland include: severe sheet and rill erosion, channel downcutting (with a loss of sinuosity) in headwaters, channel aggradation at lower reaches, and subsequent channel dredging, straightening, and lengthening (Simon and Rinaldi 2000). In southwestern Wisconsin and northeastern Illinois, the replacement of prairie and forest by agricultural land use accelerated floodplain sedimentation that averages 30-50 cm on tributary floodplains and as much as 3 - 4 meters on floodplains in lower reaches of main valleys near the Mississippi River (Knox 1987, Trimble 1993). Rates of overbank floodplain sedimentation range from 0.3-0.5 cm per year compared with post glacial floodplain accretion rates of 0.02 cm per year — a 15 to 25 times increase!

Changes from forestland to cropland often mean changes in infiltration rate (Stoeckler 1959, Hibbert 1967, Glymph and Holtan 1969, Lee, 1980). Studies of soil compaction in forests of the Lake States in the 1990s also show soil compaction following logging (Stone and Elioff 1998, 2000; Stone et al., 1999; Stone, 2000). Long-term soil productivity studies show little recovery to pre-harvest bulk densities — in spite of repeated freeze-thaw cycles (Stone and Elioff, 1998, personal communication, D. S. Stone). Often this has meant significant, decreases in tree productivity on loamy sands (Stone, et al. 1999), slight, but non-significant, increases on sugar sands (Stone 2000), and slight, but non-significant decreases on heavy clays (Stone 2000). Heavier equipment available for agricultural and forest harvesting in the 1980s and 1990s may be compacting soils enough to impact wood yields in the next rotation and to require deep subsoiling of agricultural soils beneath the plow layer.

These changes (along with land use conversion) can increase the magnitude of bankfull streamflow and causes channel adjustments that diminish favorable channel habitats. Burch, et al. (1987) described land use impacts on saturated soil hydraulic conductivity and stream flows in southeast Australia comparing 80-year old grassland (not recently grazed) to a remnant eucalypt forest. The grassland produced peak storm flows and large discharge volumes regardless of antecedent soil moisture status. The forest yielded little runoff when soil moisture was below 60% of available capacity. They attributed the difference in peak flow response to the saturated hydraulic conductivity of the grassland soil at half the value in the undisturbed forest soil. Ragab and Cooper (1993) found higher saturated and unsaturated hydraulic conductivities in woodland than in permanent pasture, and both were higher than arable soil. In a landscape vision, are we seeing soils, trees, and streams responding together?

IMPACTS TO STREAMS CONDITION: BASIN-WIDE AND LOCAL

In the Southern Lake Superior Clay Belt studies show the complete sequence of land use changes has reduced channel length by 45% though the channels still run in the same valley. This is a 45% loss of stream habitats. In northern Wisconsin, channels have down-cut 5 meters in their headwaters, remain at pre settlement elevation in their mid range, and aggrade 4 meters in the lower third of their valley. This pattern of main channel adjustment repeats throughout the Midwest with maximum down-cutting (10 meters) occurring where loess depths are greatest in western Iowa (and eastern Nebraska) (Simon and Rinaldi 2000).

Additionally, fine sands eroding from gravel and native material roads at stream crossings can fill pools in channels up to10 m wide (personal observation). This buries riffles, fills pools, and causes more frequent flooding of the floodplain. This problem is more prevalent in forest regions than in agricultural regions because road slopes at stream crossings are generally steeper than at streams in agricultural areas (Verry 2000).

IMPACTS TO STREAM BIOTA

Basin-Wide Causes

Fine sediment (silt and sand) reduces aquatic habitat diversity and biological productivity by filling pools and embedding spawning and food producing substrates (Waters 1995). Low gradient, headwater streams in the Midwest have limited flushing capacities and cumulative effects of sedimentation can persist for decades even when current sediment production has returned to normal (Richards and Hollingsworth 2000, Waters 1995).

Wang et al. (1997) showed that the index of biotic integrity (IBI) significant drops when agricultural land exceeded 50% of the basin, and large drops occurred when urban land cover exceeded 10% - 20% of the basin.

Poff and Allan (1995) conclude that the strong correlations between hydrology and fish assemblages in 34 Wisconsin and Minnesota basins suggest that changes in water flow induced by human disturbance or climate change could modify fish assemblage structure throughout the region. Peterson and Kwak (1999) tested this concept for a small mouth bass population in the

Kankakee River of northeastern Illinois. For three measurement and model periods: (1915-1925, 1977-1990, and 2060) the resulting bass densities were 65/ha, 27/ha, and 9/ha.

Land use changes from forests to agriculture were more important to bass mortality than climate change. The mechanisms yielding lower adult bass densities are caused by the longitudinal displacement of eggs and fry, and indirectly by increases in turbidity that inhibit feeding and disturb fry orientation; all of which lead to increased mortality.

Site-Specific Causes

Undersized culverts commonly cause a stream block to spawning fish because velocities exiting the culvert are faster than fish can swim (Baker and Votapka 1990). Observations illustrate site-specific examples. In one instance on an 8-m wide stream in north central Minnesota, a road fill is drained with two 1.2-m diameter culverts. During bankfull flows water velocities exiting the culverts were 2-3 m s^{-1} for over a week; much faster than the 0.6 to 0.9 m s^{-1} swimming speed of most spawning fish in the Midwest. In another instance, two 1.2 m culverts in a 7-m wide stream had exit velocities of 2.4-2.7 m s^{-1} at the bankfull stage.

CONCLUSIONS

Patric (1978) concluded that forest harvesting in the Eastern hardwood forests would not affect floods so long as the forest floor was intact. We have learned three important clarifications to that statement. First, land fragmentation and mixed land use is the norm and simple forest versus crop comparisons is an oversimplification. Second, when open land or young-aged forestland exceeds 60% of a basin small floods (1.5- to 20-year events) are increased. Third, even intact forest floors with collapsed macropores in the underlying A and E horizons have significantly reduced infiltration rates.

The 60% forest area guide applies to watersheds only 2 ½ square kilometers in size where hill slopes are 3 to 45 %. In flat basins (< 3% hill slopes), in-channel erosion does not occur in basins smaller than 25 square km.

Size channels and their floodplains in cropland areas to handle the increased bankfull flows without excessive in-channel erosion.

Matching culvert width to bankfull stream width avoids fish blocking exit velocities and reduces culvert maintenance and replacement costs.

Accelerated mechanization of forestland and cropland harvesting in the 1980s and 1990s has seen heavier equipment covering most if not the entire harvest site. This may collapse soil macropores, reduce water and air infiltration, disrupt optimum air/water mixes in the soil atmosphere and impede soil water drainage.

These conditions may cause reduced biomass production, lowered water infiltration rates and increased bankfull flow velocities in streams. In turn higher bankfull discharge can destabilize normal patterns of stream width, depth, sinuosity, and slope and accelerate in-channel erosion and sedimentation. Both higher velocities and higher turbidity can reduce fish and invertebrate production.

These landscape links and their impacts on ecosystem function need testing in many environments. Water infiltration and biomass response are the least studied of these processes and perhaps the hardest to evaluate.

In a landscape vision are we seeing soils, trees, and streams (and their biologic communities) respond together?

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