DOWNSTREAM EFFECTS OF DAMS ON CHANNEL GEOMETRY AND BOTTOMLAND VEGETATION: REGIONAL PATTERNS IN THE GREAT PLAINS

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Abstract: The response of rivers and riparian forests to upstream dams shows a regional pattern related to physiographic and climatic factors that influence channel geometry. We carried out a spatial analysis of the response of channel geometry to 35 dams in the Great Plains and Central Lowlands, USA. The principal response of a braided channel to an upstream dam is channel-narrowing, and the principal response of a meandering channel is a reduction in channel migration rate. Prior to water management, braided channels were most common in the southwestern Plains where sand is abundant, whereas meandering channels were most common in the northern and eastern Plains. The dominant response to upstream dams has been channel-narrowing in the southwestern Plains (e.g., six of nine cases in the High Plains) and reduction in migration rate in the north and east (e.g., all of twelve cases in the Missouri Plateau and Western Lake Regions). Channel-narrowing is associated with a burst of establishment of native and exotic woody riparian pioneer species on the former channel bed. In contrast, reduction in channel migration rate is associated with a decrease in reproduction of woody riparian pioneers. Thus, riparian pioneer forests along large rivers in the southwestern Plains have temporarily increased following dam construction while such forests in the north and east have decreased. These patterns explain apparent contradictions in conclusions of studies that focused on single rivers or small regions and provide a framework for predicting effects of dams on large rivers in the Great Plains and elsewhere. These conclusions are valid only for large rivers. A spatial analysis of channel width along 286 streams ranging in mean annual discharge from 0.004 to 1370 cubic meters per second did not produce the same clear regional pattern, in part because the channel geometries of small and large streams are affected differently by a sandy watershed.

Key Words: channel geometry, cottonwood, dam, forest, Great Plains, riparian, sediment

INTRODUCTION

Most large rivers in the Northern Hemisphere have been dammed (Dynesius and Nilsson 1994), and downstream lotic and riparian ecosystems have been greatly altered (Brinson et al. 1981, Stanford et al. 1996). Prediction of the downstream changes in channel geometry and biotic community composition is complicated by the diversity of possible responses. Following dam construction, rivers may become wider, narrower, shallower, or deeper; time necessary for the response ranges from months to millennia, and the direction of the response may change over time (Petts 1979, Williams and Wolman 1984). Response of the riparian ecosystem is equally complex, even within the Great Plains (Friedman et al. 1997). For example, downstream cottonwood forests have typically decreased in Alberta (Rood and Mahoney 1990) but increased in Nebraska and Colorado (Johnson 1994). The diversity of dam effects occurs because channel response is mediated by fluvial processes that vary in relative importance from site to site. Where the dominant fluvial processes are known, methods for predicting the amount and timing of downstream channel response can be developed (Osterkamp and Hedman 1981, Church 1995), and the response of the riparian vegetation can be predicted (Scott et al. 1996, Johnson 1998). In this paper, we explore regional variation in the response of channel geometry to upstream dams in the Great Plains and part of the Central Lowlands in the United States. We relate this variation to the geologic and climatic factors that control local fluvial processes and discuss the consequences for riparian forests.
Ecological Characteristics of Riparian Pioneer Species

In Great-Plains riparian ecosystems, the narrow zone moist enough to support woody plants is also subject to frequent riverine disturbance. As a result, Plains riparian forests are often dominated by pioneer species, especially plains cottonwood (P. deltoides Marshall subsp. montilfera (Aiton) Eckenwalder), peachleaf willow (Salix amygdaloides Anderss.), and sandbar willow (Salix exigua Nutt.). In addition, the exotic shrub salteedar (Tamarix ramosissima Ledebour) has become a dominant pioneer in the southern Great Plains and is naturalized as far north as southern Canada (Great Plains Flora Association 1986, Brock 1994). These pioneers have similar seedling-establishment requirements (White 1979). Freshly deposited alluvium typically provides ideal substrate for germination and establishment of abundant wind- and water-dispersed seeds, which are released beginning late each spring in association with peak river flows (Horton et al. 1960, Scott et al. 1993, Johnson 1994). The seeds lose germinability within a few weeks (Moss 1938, Ware and Penfound 1949, Horton et al. 1960). Riparian pioneers are intolerant of shade and rarely become established from seed under trees or herbs (Johnson et al. 1976, Friedman et al. 1995). Seedlings require a continuously moist surface during the first week or more of growth (Moss 1938), but adults typically avoid surface drought by extending roots down to the water table (Segelquist et al. 1993).

Riparian sites bare and moist enough for seedling establishment of riparian pioneers are usually close to the channel and subject to disturbance by the stream. Although pioneers are tolerant of burial and able to sprout from stems or roots, floods and ice scour typically cause high mortality of seedlings and saplings (Johnson 1994, Scott et al. 1996, Auble and Scott 1998). Therefore, establishment from seed occurs only in locations that are moist, bare, and protected from future intense disturbance (Everitt 1968, Bradley and Smith 1986, Johnson 1994).

Reproduction via sprouts from roots or stems may prolong occupation of a site (Rood et al. 1994). However, in the absence of physical disturbances such as floods, cottonwood and willow tend to be replaced by more shade-tolerant plants. In the eastern Plains, pioneer cottonwood and willow are replaced by a diverse bottomland hardwood forest (Bruner 1931, Weaver 1960, Johnson et al. 1976, Currier 1982). For example, in central Kansas, bottomland dominants include green ash (Fraxinus pennsylvanica Marsh.), bur oak (Quercus macrocarpa Michx.), American elm (Ulmus americana L.), box elder (Acer negundo L.), and hackberry (Celtis occidentalis L.; Weaver 1960). Compared to cottonwood and willow, these species are typically slower to disperse to new sites and are less tolerant of inundation, burial, physical damage, or soils low in organic matter (Johnson et al. 1976, Teskey and Hinckley 1978). Forest diversity decreases westward until only pioneer species remain. Thus, in much of the western Great Plains, the climax native bottomland community is not forest but shrubland or grassland (Hefley 1937, Lindauer 1983), and maintenance of forest is dependent upon physical disturbance, especially floods (Friedman et al. 1997, Auble and Scott 1998, Rood et al. 1998).

Downstream Effects of Dams on Channel Geometry and Forest Establishment

Dams typically decrease downstream peak flow and sediment load. Many different changes in channel geometry can result. For the purposes of this regional analysis, we only consider changes in planform (the two-dimensions of the ground surface as viewed from above). Vertical changes, especially channel-downcutting, are discussed by Petts (1979) and Williams and Wolman (1984), and their effects on riparian vegetation have been documented by Snyder and Miller (1991) and Rood et al. (1995). In the Great Plains, the two most common planform changes downstream from a dam are channel-narrowing and reduction in channel migration rate (Osterkamp and Hedman 1981). These two processes can have different effects on riparian pioneer forests.

If a dam reduces peak flows below that necessary to rework the entire channel bed, then vegetation may become established on the bed. The newly established vegetation promotes deposition of cohesive fine sediment and increases resistance to erosion (Smith 1976), thus stabilizing the channel at a narrower width. Furthermore, because sand and gravel are transported along the bed, a dam-related decrease in the load of such sediment decreases the equilibrium channel width necessary to transport the bedload. Because portions of former channel bed are bare, moist, and relatively safe from disturbance, they are ideal establishment sites for pioneer riparian vegetation. Therefore, post-dam channel-narrowing is typically associated with a pulse of woody pioneer establishment. This pulse ends when a new equilibrium width is attained. Further pioneer establishment occurs only to the extent that the channel is able to migrate.

Channel migration typically promotes establishment of riparian pioneers by providing new bare, moist surfaces such as point bars suitable for seedling establishment. If a dam reduces peak flow and sediment load, the rates of bank erosion and bar deposition are typically reduced. This effect may be exacerbated by...