Appendix 28

Geomorphology of the Lower Flathead River

The following description of the geomorphic processes on the lower Flathead River is excerpted from *Riparian Inventory of the Lower Flathead River: Final Report* (Hansen and Suchomel 1990)

GEOMORPHOLOGICAL CHARACTERISTICS

The Geomorphology of a Dynamic River System

The study of a river system involves the interpretation of a continually changing water-influenced (fluvial) landscape. The erosional and depositional pattern of the river helps maintain the diversity of plant communities on the floodplain. The distribution of various communities depends on the way the river meanders. In turn, the rate of meandering determines the proportion of floodplain communities considered to be in the pioneer, early seral, mid seral, late seral, or PNC (potential natural communities) stage of succession. Where the river meanders often, few stands progress to later successional stages. Near the outer edges of the floodplain, the effect of the river is less pronounced, allowing later successional stages to develop.

The width of the floodplain depends on the geology of the area. Floodplains may be narrow and confined because of highly resistant materials, or may be broad as in regions with highly erodible materials (e.g., sedimentary plains). Typically, rivers meander like a whip or snake across their floodplain. Lateral movement of the river starts a dynamic series of vegetation events. As water moves downstream, it erodes established banks, typically covered with riparian vegetation in different stages of development, on outside curves and deposits fresh alluvial materials on the point bars of inside curves. The fresh, bare, moist alluvium provides a suitable seedbed for the establishment of pioneer seedlings of tree or shrub species such as *Populius trichocarpa* (black cottonwood) and *Salix exigua* (sandbar willow). Each new site forms a distinct band or terrace with each band being even-aged and with gaps in ages between the bands. The ages of the bands are progressively older on older terraces. As the river moves away from sites of previous deposition and continues to downcut, soil water recharge from channel seepages decreases, making these sites (terraces) drier.

Simultaneously, an additional process is occurring. During high water periods (e.g. floods), the river may overflow its banks thereby dramatically increasing the rate of aquifer recharge. When this happens, water velocities slow dramatically, and the river drops its sediment load. The deposition of new alluvial material on top of streambanks results in the formation of alluvial terraces at various elevations above the river. Recent or young terraces are slightly higher than the river. Through downcutting by the river, the river bed is lowered, and relief between river and terrace is increased. In addition, the terrace itself increases in elevation as the result of sediment deposition from frequent flooding. Higher or older terraces experience fewer floods of shorter duration and lower intensity than those occurring on lower or younger terraces. Relief between a terrace and the river can also increase if the terrace has been missed by the meandering of the river (Hansen 1980). If certain parts of the floodplain stay undisturbed for a long enough time, their relief with respect to the river may increase to a point where they are only rarely flooded. These terraces are considered old or mature alluvial terraces and can continue development to PNC without the modifying influences of floods. In time older terraces begin to accumulate organic matter, become more moderate in their water regime, and do not suffer the extremes (e.g. frequent or prolonged flooding) of the lower floodplain environment. The highest terraces therefore show the most advanced plant community development.

Vegetational Influences on the Shape of a Stream Channel

Newly established riparian vegetation on recently deposited sediments act as both an adhesive in holding the soil together and as a protective boundary layer to the erosive forces of the flowing water. The degree which vegetation controls channel shape depends on its ability to improve the inherent substrate stability. Assuming materials available to an active bar are fairly uniform in size, resistance, and type, vegetation may provide the added stability that controls channel formation.

Many researchers have documented changes in channel geometry after vegetation loss. Many researchers have also documented changes in riparian vegetation following channel or streamflow adjustments caused by hydroelectric or irrigation dams. Generally, floodplain vegetation depends on the stream water supply, stream morphology, ground water supply, and soil substrate, while simultaneously the vegetation influences each of the afore mentioned characteristics.

HYDROLOGICAL FEATURES OF A RIVER SYSTEM

The flow regime of a river, as represented by its hydrograph, controls the forces determining the shape and water supply of most riparian systems. Generally, a river's flow regime interacts with the vegetation and floodplain substrates with each influencing and being influenced by the other. Flow regime is usually described in terms of magnitude (size), duration, and frequency of events. Both the infrequent extreme events and the more frequent less extreme events shape the floodplain, but in very different ways. For example, Wolman and Miller (1960) state although extreme events play an important role in shaping some floodplains, it is the less extreme and more frequent flooding events that probably are the most influential in terms of both positive and negative impacts on the riparian area.

Recognizing the controlling characteristics of a watershed and the floodplain is important in determining the rates at which water is released into a river system. For example, the supply of water in a watershed is typically controlled by precipitation and the interaction of the geology, soils, and vegetation of the area.

Precipitation on impermeable soil and geologic units will enter the stream channel rapidly. On the other hand, precipitation on permeable, well-vegetated soil will enter a ground water system and may not reach a stream channel for many seasons.

One way the floodplain and stream channel interact is through temporary water storage in the streambanks. Although extreme highs may have a totally different effect than more frequent lower discharge events, any event that results in over-bank flooding affects the floodplain. In addition, low points on the hydrograph also affect the floodplain through direct reduction in water supply to the flora and fauna of an area.

The size, shape, and gradient of a river channel will determine the depth of water in the channel (Butzer 1976). Assuming a constant volume of water, the water column will be higher when confined in a narrow channel than when spread out over a wide channel. Streamflow that is confined by narrow channel, as in a narrow V-shaped canyon, has a higher water column, which results in a higher hydraulic potential. This in turn increases the rate of exchange between the channel and banks as compared to a wider channel. In addition, a narrow water column contacts more streambank surface area resulting in increases in the flow rate from the channel to the banks and floodplain. However, low water columns resulting from lower flows may permeate the channel bottom, by having limited contact with the banks and floodplain. Channels that widen or deepen increase the flow capacities of the stream channel. However, this increased flow capacity may have a dramatic affect on water stored by reducing overbank events. In a natural unregulated system, channels generally overtop their banks every year or every other year.

FLOODPLAIN SOILS

The soils of the Lower Flathead River floodplain are developed on recent alluvial deposits and vary widely in texture. Silts, sands, and clays deposited by past floods or by erosion from the surrounding hillsides are present in lenses of various thickness, and in most places soil profile development is minimal with only A or C horizons usually distinguishable.

Flooding plays an important role in the development of soils in riparian zones. Contrary to the situation in most upland sites, the surface soil texture of riparian communities on active floodplains can change quickly and dramatically. The first deposits on the point bars (the inside curve of a meander) are typically sandy. Unless these sites are later flooded and fine-textured sediments (silts and clays) deposited on top of them, the original texture stays essentially unchanged. However, situations do occur when there is a burial of well-developed soil profiles. During floods, as much as 1 to 2 m (3 to 6 ft) of silt can be deposited, resulting in complex layered soil profiles of buried soils and intermixed lenses of sand, silt, and clay. Typically, riparian communities near the river, where flood stream flow is greatest, are often covered with sandy deposits (coarse-textured materials) while sites flooded farther away from the river may receive only finer textured materials.

In other situations, erosion from the surrounding hillsides will deposit clay and silt over coarser-textured materials. Sometimes major storm events have caused severe erosion of the adjacent hillsides, resulting in tremendous amounts of sediment dumps that take on the appearance of an alluvial fan. Through time, the clay from the surrounding shale hillsides may cause a perched water table to occur, thereby allowing riparian species to occur on what seems like upland sites.

Organic matter differences among terraces can be explained by differences in the age of the terrace. Newly formed young terraces contain almost no soil organic matter. Older terraces however, have had more time for organic matter to accumulate and to become incorporated into the soil structure. In addition, high organic matter build-up in the surface soils is possible only in stands on higher older terraces infrequently disturbed by floods. On low terraces, organic matter is either buried or exported, resulting in low organic matter content. Generally, younger terraces have low organic matter content and therefore, a low available water capacity. Older terraces have higher organic matter content, resulting in higher available water capacity values.

Similar to the organic matter content and available water capacity, soil fertility also improves as the terraces age. Wilson (1970) and Johnson and others (1976) reported that in young terraces, the total nitrogen content was very low but increases greatly in older terraces. Johnson and others (1976) found the trend for soil phosphorus and calcium to be similar to nitrogen. However, potassium values approximated a bell-shaped curve, with the concentrations in the older terraces similar to those in the younger terraces. Both researchers suggested the decline in replaceable potassium levels in older terraces may be resulting from leaching and low flood frequency. Older terraces have had more time for leaching to occur, and their location on higher terraces with a low flood frequency results in a reduced input (deposition) of nutrient-rich silt and clay. Johnson and others (1976) suggested a combination of terrace age and lack or replenishment may be responsible for the lower concentration on older terraces.

Generally, as the alluvial terraces along the Lower Flathead River mature, there is a corresponding change in the soil parameters, thereby providing a more suitable environment for the establishment of the more mesic tree species *Pinus ponderosa* (ponderosa pine), *Juniperus scopulorum* (Rocky Mountain juniper), and *Populus tremuloides* (quaking aspen) in cottonwood stands.

SITE REQUIREMENTS FOR COTTONWOOD AND WILLOW RECRUITMENT

Seedbed Requirements

Cottonwoods can regenerate by one of two methods: (1) clonal propagation through suckering (new shoot production from existing roots), and (2) seed dispersal. In general, the suckering capabilities of cottonwoods decrease dramatically as they mature. Therefore, the principle method of cottonwood regeneration is through seedling establishment following seed dispersal.

Seedbed requirements of pioneer cottonwoods and sandbar willow species have been well documented (Read 1958, Everitt 1968, Wilson 1970, Johnson and others 1976, Noble 1979). Suitable sites are moist, barren, newly deposited alluvium that is exposed to full sunlight. Generally, these sites are found along a river and its tributaries in sites with recent sediment deposition, such as point, side, and mid-channel bars; delta bars; and islands.

These pioneer species share several adaptations that ensure their establishment. A large variation in seed dispersal dates often happens even among adjacent individuals, thereby providing for seed dispersal over a long time (Schreiner 1974). The seed dispersal time period for the pioneer species along the Lower Flathead River is around 4 to 6 weeks, occurring from the first of June to mid- July. However, although the dispersal period may be fairly long, the seed is only viable for around 2 weeks. Large numbers of seeds are produced with the attached plumes providing for dispersal by both the wind and the nearby river. Bessey (1904) estimated the number of seeds produced by one mature cottonwood to be around 28 million. The hairs of the plume of the cottonwood seeds are instantly attached to either a moist alluvial surface or the surface of the river, often forming extensive mats of trapped seeds. In addition, Ridley (1930) observed that the capsules of willow catkins open on contact with the water surface thereby releasing the plumed seeds. These adaptations all tend to increase the possibility that at least a small part of the seed crop will reach a favorable germination site before experiencing a complete loss in viability. Moss (1938) showed that the substrate must be maintained in a moist condition for at least a week to ensure successful germination and establishment. Germination occurs within 8-24 hours on most moist surfaces. However, the seed crop will fail if the substrate dries during the fast several days after germination.

Research throughout the United States suggests that the size of the recently deposited sediments control the species composition of the pioneer stands. Generally willows are more often observed on finer-textured sediments while cottonwoods develop on more coarsely textured alluvium (Henley 1937, Ware and Penfound 1949, Shelford 1954, Wistendahl 1958, Everitt 1968, Lindsey and others 1961, Wilson 1970, Johnson and others 1976). Generally, dense stands of willows occupied sites where the flow of the river decreased, resulting in the settling out of the finer-textured materials. Examples of these sites are old meander channels, old oxbow channels, overflow or side channels, or backwater areas. On the other hand, cottonwoods were generally most abundant on gravel or sand bars.

During the summer, survival of seedlings varies in relation to their proximity to water and the water table. This distance is dependent upon the topography of the bar and the recession of the river. Commonly a band of seedlings, from 1 to 3 m (3 to 9 ft) wide is found on these bars. Width is dependent upon the slope of the bar with narrow strips occurring on the margins of the steeper bars. Drought-induced seedling mortality is apparent on sites where the water level has dropped leaving exposed bars. Aside from drought-induced mortality, direct heat injury can kill seedlings during summer months. In addition, seedling survival depends upon sediment movement. The abrasive nature of the sediments and the velocity of the river may wash away previous year's seedlings. These same factors affect saplings, but mortality rates are generally lower than those for seedlings. Older saplings often show basal scars on the upstream side of their stems that have resulted from abrasion by sediments carried during high flows.

Survival of these pioneer species after establishment is directly related to the duration of inundation, amount of high flow scouring, and the age of the plants. Complete inundation of plants results in mortality after a certain species-specific time period. Recent work has found saplings of *Populus deltoides* (Great Plains cottonwood) and *Salix exigua*, (sandbar willow) showing good survival rates after 8 weeks of total inundation. Generally, partially inundated plants survive longer than completely submerged plants and older plants survive inundation longer than younger plants.

Flooding Requirements

In western Montana, the months of March through early July generally constitute the principal high-flow season. The cottonwoods and willows are shedding seeds from early June to late July, when the rivers are falling through the various elevations of the bars. With this drop in elevation the river has provided the moist substrate needed for the germination of cottonwood and willows. With a reduction in the drop of the river, the recently colonized substrate does not become quickly desiccated as happens when the river continues to fall to a much lower elevation. On those sites with nearly uniform and coarse-textured materials, the possibility of much upward capillary movement of water is negligible. However, fine-textured materials will have more favorable water holding capabilities, and will provide water to the cottonwoods or willows for longer periods of time, even with a slow drop in the water table.

In a study along the Minnesota River in west-central Minnesota, Noble (1979) found that the sites of cottonwood and willow establishment are far below high flood elevations. In fact, he found them to be near the end of the actual flooding period. He stated that because an appropriate and constant river elevation does not happen every year, establishment therefore only happens during those occasional years with favorable river fluctuations. In his study, Noble (1979) found that the river elevation stabilization happens when a cold airmass halts spring snowmelt over the watershed or with the cessation of spring rains.

In a study on island development in the Mississippi River, Shull (1944) suggested that several years of low water is needed to provide the necessary conditions for the establishment of cottonwoods or willows. However, it seems that a distinct lack of moisture resulting in a poor (if any) survival rate of cottonwood/willow seedlings would result instead of substrate conditions (recently deposited moist, bare, alluvial material) necessary for the successful establishment of cottonwood and willow.

Therefore, there seems to exist a critical elevation on bars where the seedbeds need to be high enough to avoid drowning by later floods, but low enough to allow newly established seedlings to tap into the water table.

Bar Development

Generally, there are four major bar formations that result in the deposition of alluvial materials suitable for the recruitment of pioneering species and they are: 1) point bar, 2) side bar, 3) mid-channel bar, and 4) delta bar.

Point bars typically occur along the inside of a meander curve or in those parts of the river where river curvature is not sufficiently developed to be regarded as a meander. These bars show a progression of elevation zones from the river edge to successively older terraces. These zones (terraces) do not have uniform surfaces but are typically covered by a series of ridges and swales resulting from the trapping of sediments at the base of woody species. These woody species typically form strips parallel to the river. The bars tend to be semicircular with the round side next to the river. Frequently, an overflow channel running along the base of the older terrace can be observed. The vegetation patterns on these terraces exhibit an age gradient from young seedlings of the same age on the youngest terraces to older, even-aged groups on successively older terraces.

Side bars (bars adjacent to the straighter sections of the river) are normally low in elevation to the river with relatively uniform low-angle slopes from the river edge to the first major terrace. Side bars are usually quite narrow and linear in shape. Generally, side bars usually lack vegetation except for a dense patch of annual herbaceous species and a narrow zone of cottonwood or willow seedlings that germinate immediately adjacent to the river. These strips of seedlings are generally either killed by summer drought caused by the continual decreased in flow rates which results in a lowering of the depth of the river, or are washed away or drowned by annual high spring flows.

Mid-channel bars are those bars found within the channel and generally become more noticeable during low-flow periods. These mid channel bars can develop into islands if river conditions are favorable. During low flows, these bars may become vegetated either by cottonwoods and willows or by herbaceous vegetation. Again, these bars of seedlings or herbaceous vegetation are either killed by summer drought caused by the continual, decreased in flow rates or are washed away or drowned by annual high spring flows.

Delta bars form immediately downstream of the confluence of the main river with a tributary. As the faster flowing tributaries enter the slower flowing main river channel, there is a decrease in velocity resulting in a deposition of sediments. Generally the greater the volume of water carried by the tributary, the more sediment that will be transported. These delta bars generally form along the side of the channel immediately downstream of the confluence. However, if the tributary represents a large stream and if river conditions are appropriate, islands may form a short distance downstream. This generally happens when the tributary enters the main river channel on the outer part of a curve and the main river's current is too swift to allow deposition of sediments to happen. These sediments are carried by the river and deposited when the velocity decreases.

Of the four types of bars discussed, the point bar, mid-channel bar, and the delta bar represent the greatest potential sites for cottonwood/willow recruitment.

Bars take on a seemingly endless pattern of development, depending on the velocity of the river, the position of the bar in relationship to the floodplain, the relationship of the bar within the river channel, the amount of sediment in the system, and the impacts of floods caused by major storm events, spring runoff, or ice jams. The wide array of disturbances all work at different rates and degrees to influence the size, shape, and location of the bars. However, all bars tend to undergo the same type of developmental pattern. The formation of a new bar typically happens over a period of time. (However, major flood events may produce a bar in a very short time frame.) During low flows, bars may become exposed. If conditions are favorable, a dense stand of cottonwood or willow seedlings will become established. However, if the bar is exposed after the time of viability for cottonwood or willows (after the first of August), the bar may become vegetated by herbaceous species such as white sweetclover, redtop, rayless alkali aster, foxtail barley, pointed barnyard-grass, bristlegrass, nodding beggar-ticks, common cocklebur, water smartweed, common willow-herb, yellow sweetclover, or field mint. In either case, the newly established vegetation acts as a filter thereby trapping sediments and building up the height of the bar. During high flows the bars may be completely covered by water with the newly established vegetation being drowned, completely buried by sediments, or washed away. This sequence of events may happen over many years until the bar is high enough so that the influence by the river is greatly diminished. It is important to keep in mind that frequently, bars never develop because of a variety of river-influenced events. In some situations, the riverbed (channel) may move and erode away a bar along with any seedlings and saplings growing on it. These types of landform changes are typically most evident where the river shifts position in relatively unstable areas (e.g., tributary confluences or sharp meander bends).

FLOODPLAIN SUCCESSION

The riparian zone is a dynamic environment. Erosion and deposition, meandering channels, backwater areas, overflow channels, abandoned meander channels, island formation, and high and low water periods all contribute to the creation or destruction of a wide diversity of plant communities. As conditions are changed by river processes, species composition of the sites change accordingly.

On rivers not dammed or channelized, the river is free to move back and forth across its floodplain, resulting in stands of vegetation in various stages of succession. Where meanders move rapidly, climax stands may occur only rarely. Where the meanders are moving slowly, the silt deposition during flooding or downcutting of the channel may create higher, better drained conditions at particular sites, allowing less flood tolerant species to become established and often dominate the site.

Wolman and Leopold (1957) showed that although rivers may potentially erode any existing terrace on the floodplain, they do not normally move continuously from one side of the valley to another. Along the Missouri River in North Dakota, Johnson and others (1976) found that the river meanders nearer the center of its meander belt than along the edge of the floodplain. This results in the washing away of communities in the center of the floodplain on a frequent basis. In this zone, the pioneering species of cottonwood and willow are recycled relatively rapidly with few stands capable of reaching advanced successional stages. In contrast, the outer edge of the floodplain is influenced less by the river meander thereby allowing successionally advanced stands to occur. Many successionally advanced stands are completely absent of any pioneer species. A low erosional frequency near the edge of the floodplain allows the mature terraces to become elevated above the river level because of deposition from overbank flow and downcutting of the river channel. Therefore, terrace elevation and age are related.

Succession along rivers in western Montana typically begins when pioneer species colonize fresh alluvial materials deposited by the river. The fresh, fully exposed alluvium provides a suitable seedbed for the establishment of pioneer seedlings such as black cottonwood and sandbar willow. Seeds of cottonwoods and willows are extremely delicate and require a moist soil surface (but not flooded) for germination and early seedling survival (Wilson 1970. Hansen 1980, Boggs 1984). Cottonwoods and sandbar willow are extremely intolerant of shade, needing full sunlight for maximum growth. These conditions are typically met only on recently exposed alluvial material along the water’s edge. In addition, seeds of cottonwood and willow are viable for only a short period, making frequent flooding a necessity for successful seedling establishment. If the required environmental conditions are not present at the time of seed dispersal or shortly thereafter, seedling establishment will not happen. The bars may then become vegetated by a wide variety of herbaceous species (see the discussion under the heading of Bar Development for a list of these species).

Both cottonwoods and willows are adapted to frequent flooding. During floods, their shoots are often buried under deposited sediments. New sprouts then form, rising vertically through the sediment (Everitt 1968). Cottonwoods and willows can produce new sprouts from the roots and stumps of damaged young trees.

Most bars have both cottonwoods and willows establishing simultaneously. (However, some sites may be populated by only one species.) As pioneer seedlings of cottonwood and willows continue to grow, a dense thicket dominated by willows develops. After about 15 years, cottonwood saplings overtop the willows, shading them out (Wilson 1970). Sites then become dominated by a dense, closed canopy of sapling cottonwood with a very sparse understory. As trees mature, stands begin to thin, and as succession continues, additional species invade.

The relatively open canopy of the tall and widely spaced mature cottonwood community allows enough light to penetrate to permit an understory to develop. The understory may consist of the tree species ponderosa pine, Rocky Mountain juniper, and quaking aspen and associated shrub species such as red-osier dogwood, common chokecherry, western serviceberry, currants and gooseberries, western snowberry, woods rose (Hansen and others 1989). If the site is not heavily affected by human activities or heavy grazing, these species will eventually (after approximately 75 to 100 years) replace the mature cottonwoods, forming stable climax communities.

Clearly each species responds individualistically to the many environmental changes happening along the age gradient of the terraces, and often subtle environmental differences among terraces of similar age result in differential establishment of the potential natural community. Consequently, succession proceeds in different directions from the initial cottonwood/willow communities, eventually resulting in sites with different potential natural vegetation.

Finally, an interesting feature of many floodplain communities are linear openings that run parallel to the river. Trees are typically absent, and these sites are slightly lower (0.5 to 1 meter) than the rest of the floodplain. These openings result from uneven deposition when the terrace was formed, creating sites too wet for cottonwoods or willows to germinate or persist (Hansen 1980), or were first vegetated by herbaceous species that made the sites unfavorable for cottonwood or willow establishment. In other locations, these depressions represent abandoned meander channels, overflow channels, or oxbow lakes. Depending on the amount of water present and the type of sediments (e.g.. coarse vs. fine textured sediments), these overflow channels or oxbow lakes may be dominated by species of common cattails and hardstem bulrush.

DAM IMPACTS

Flow-regulation structures can affect the normal dynamics of a river system. Generally, the duration, magnitude (size), and frequency of flooding, rates of sedimentation, and rates of lateral migration of the riverbed are all influenced by a dam. The duration, magnitude (size), and frequency of flooding directly affect the rate and amount of aquifer recharge.

In a study along the Milk River of southern Alberta and northern Montana, Bradley and Smith (1986) reported that decreased flood frequency and magnitude, and reduced point bar sedimentation and lateral movement along the downstream reach below the Fresno Dam coincided with a significant reduction in cottonwood densities when compared with the upstream reach. However, cottonwood populations established before the Dam was built showed no significant differences in densities between the two reaches.

Bradley and Smith (1986) found that along the Milk River in southern Alberta (above the Fresno Dam), conditions for seedling recruitment leading to long-term survival of cottonwoods happened an average of once in 5 years or more when the maximum daily flows during the period of seed dispersal (June to early July) exceeded the 2-year return annual flood. They suggest that these peak flows, accompanied by sedimentation, produce ideal moist, bare seedbeds at elevations on point bars sufficiently high to avoid further disturbances from subsequent flooding during the first few critical years of growth. Therefore, there is a critical elevation on bars where seedbeds are high enough to avoid drowning by later floods, but low enough to avoid desiccation (drought-induced mortality). On the Milk River below the Fresno Dam, these conditions are not currently being met. They felt that this shows that flooding and sediment deposition on bars downstream of the dam during the critical period of seed dispersal is not enough to produce proper seedbeds at a high enough elevation above the river to reduce mortality of seedlings through drowning and possible erosion in subsequent but minor flooding events.

Without adequate postseedling survival, Bradley and Smith (1986) found that the cottonwood population downstream of the dam had declined. They felt its long-term survival was threatened and suggested that if water storage reservoirs are necessary, artificial human-induced floods should be considered for managing a self-perpetuating cottonwood forests on floodplains. Otherwise, they felt intensive planting and watering of seedlings would be necessary to maintain cottonwood communities. A "do-nothing" approach would only lead to the slow elimination of cottonwood stands, in which the youngest trees will approximately equal the age of the dam and reservoir. With most of the North American prairie rivers now regulated by dams, Bradley and Smith (1986) predict that most of the floodplain cottonwood forests will be eliminated by the end of the next century, unless dramatic management changes happen.

In a similar study of floodplain communities along the Missouri River in central North Dakota, Johnson and others (1976) found the placing of dams on the Missouri River has resulted in a dramatic reduction in the density of small cottonwood trees. They felt that the low average density of small cottonwood trees is proof that environmental conditions have become less suitable for the germination and establishment of cottonwood forests. Johnson and others (1976) stated that the rapid lateral movement of the river bed is vital for the maintenance of cottonwood sites on the floodplain. They felt the reduction (or complete elimination) of flooding and subsequent reduction in the meander rate is resulting in a decline in small cottonwood trees. If current conditions continue, magnificent and expansive stretches cottonwood forests, currently a dominant feature of the Missouri River landscape, may cease to exist.

In a study on the dammed St. Mary River, the dammed Waterton River, and the undammed Belly River in southern Alberta, Rood and Heinze-Milne (1989) compared impacts of dams on cottonwood forests. They found that these irrigation dams directly influence cottonwood forests along the two rivers (St. Mary and Waterton Rivers) by directly reducing the volume of water discharged below the dams. In addition, the large St. Mary and Waterton reservoirs slowed the velocity of the water entering the reservoirs, thereby resulting in the settling out of all sediments in the reservoirs except for fine clays. This results in a downstream discharge of relatively clear "hungry" water absent of any bed load or suspended material resulting in dramatically reduced downstream sedimentation process. This in turn has a tremendous affect on the recruitment of new sites favorable for cottonwood/willow seedlings (Bradley and Smith 1986, Rood and Heinze-Milne 1989, Everitt 1968, Johnson and others 1976, Noble 1979).

Studies indicate that the recovery of suspended sediment loads downstream of a dam is quite variable and may need up to one hundred miles for the recovery to happen (Williams and Wolman 1984). However, it is important to remember that the suspended sediment loads can be increased if the tributaries downstream of a dam transports high sediment loads. In their study in southern Alberta, Rood and Heinze-Milne (1989) found no evidence of recovery of the gallery forests within the 25-mile segments they studied downstream from the dams.

Finally, Rood and Heinze-Milne (1989) felt the major reason for the reduction of riparian forests downstream of the dams on the St. Mary River and the Waterton River was caused by drought-induced mortality, particularly of seedlings. Flooding and sedimentation is essential for seed germination and establishment. Because of small seed size, and small seedling root system, cottonwoods are particularly prone to drought-induced mortality (Read 1958). Therefore, adequate soil moisture conditions must be maintained throughout the growing season if the newly established seedlings are to survive. The river downstream of a dam is typically manipulated to such a degree that these conditions are extremely difficult to meet.

ICE IMPACTS

Ice can have a dramatic affect on the floodplain. Typically, ice influences the floodplain landscape by either one of two ways: (1) mechanical damage or (2) flooding (inundation). Mechanical damage involves the following: (1) the “laying down” or “bending over” of the younger cottonwood or willow species, (2) the physical “shearing off” of the stems, (3) the actual “pulling out of the ground” by the frozen ice that surrounds the main stem, and (4) the “tilting or pushing over” of mature trees.

Typically the younger alluvial terraces are most susceptible to mechanical damage by ice. As the ice either melts or flows away, the flexible stems assume their former upright positions. Only under infrequent circumstances does the ice shear the stems off at ground level.

An interesting adaptation by the cottonwoods and willows involves the ‘bending over” or “laying down” of the seedlings and saplings. Sometimes ice flows “gouge out” parts of the streambank or the upstream portions of islands.

Many upstream parts of islands take on the appearance of a boat that has been rammed by an unmovable object. Under these circumstances, the once vertical main stems of the cottonwood or willow saplings, and sometimes the pole stage as well, are parallel to the ground with the lateral branches having assumed a vertical, mainstem position. Aside from the deformed trees, large mounds of gouged-out or scooped-up sediments are often observed on the upstream part of islands.

An infrequent situation involves the physical removal by the “pulling out of the ground” of the main stem of the cottonwood or willow. This happens when ice may form around the above ground stems thereby anchoring the stems to the ice. If the river level is increased by either human-caused events (hydroelectric dams) or by natural events, the ice will be pushed or floated upward. If the water level is raised high enough, the ice will “pluck out” those woody species frozen to the ice flows.

The final type of mechanical damage by ice involves the “tilting or pushing over” of mature trees. This happens when the river backs up because of localized ice jams during spring break-up. The results are either minor or sometimes, major flooding of those terraces next to the river. If the, terrace is an older one populated by mature cottonwood, the physical force of the ice chunks in combination with a rapid river velocity, will lead to the tilting of the mature trees in a downstream direction. Some stands may show clear evidence of this phenomenon. If the river velocity is not high enough to physically tilt the mature trees, the trees may still show the effects of ice movement by having the upstream portions of the trunk’s bark partially removed by the mechanical action of the ice.

The other major impact by ice involves flooding and subsequent sedimentation. This typically happens when ice flows form a dam (called ice jams). Behind the ice jam the river begins to overflow its banks and flood the lower (younger) terraces. As the water velocity decreases, it immediately begins to drop its load. Along the Missouri River in North Dakota, Johnson and others (1976) found silt deposits up to 2 m (6 ft) in depth caused by a single ice jam.

Aside from the deposition of sediments, there is usually a tremendous release of water that is sent rushing downstream when the ice jams breakup. If the volume of released water is large enough, it can cause severe flooding problems downstream and lead to the main river channel being completely displaced in certain locations. This results in the formation of new features such as abandoned meander channels and oxbow lakes. When this happens, the natural equilibrium (sinuosity) of the river is changed and the river immediately begins to find its new "balance." Finally, ice flows that have been deposited on the streambank can have a tremendous affect on riparian vegetation. The physical weight of the ice can either "lay down" the vegetation or can break the stems of larger woody plants such as shrubs and saplings/pole stages of various tree species.