Flood Plains

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The term flood plain is defined by the American Geological Institute as ‘the surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river in its existing regime and covered with water when the river overflows it banks’. This definition of flood plains includes only seasonally or episodically inundated land, but in fact many flood plains also contain water bodies that are permanent or semipermanent. These water bodies include floodplain lakes and channels, as well as shallow wetlands (sometimes called backswamps) that are separated from the river by levees. From the standpoint of flood plains as inland waters, these permanently wet areas can be distinguished from land subject to temporary, albeit sometimes protracted, inundation resulting directly or indirectly from a rise in river level. Seasonal or episodic inundation strongly affects the more permanently wet areas, often completely replacing their surface water and changing the environment for aquatic life. Thus the hydrology and ecology of floodplain water bodies characteristically show strong seasonal dynamics.

The earlier-mentioned definition of a flood plain often does not correspond with how floodplain ecosystems are delineated for ecological studies, which tend to include more distal or slightly elevated lands that originated as flood plains and are contiguous with an active floodplain, but may now rarely or never be inundated by the parent river. Yet these areas tend to share ecological characteristics with active flood plains for several reasons that are discussed later, and the transition between active and relict flood plains may not be clear.

Examples of Floodplain Environments

Remotely sensed images of contrasting types of floodplain environments are depicted in Figures 1–7. Images of four large South American flood plains (Amazon, Madre de Dios, Pantanal, and the Llanos de Moxos), as well as the Cooper Creek system in Australia (Figures 1–5) depict the diversity of landforms, water bodies, and vegetation in large flood plains with minimal human disturbance. Examples where floodplain hydrology has been strongly altered are shown for the Kalamazoo River (Figure 6) and the Mississippi River (Figure 7). The ensuing discussion will refer to these images. In addition, photos of many of these sites appear in the online Flood Plain Photo Gallery (cite web site here).

Geomorphological Processes on Flood Plains

Flood plains are built of alluvial fill that normally originates as sediments carried by the parent river and deposited as point bars along the migrating channel, or during overbank flooding. Hydrologists refer to bankfull discharge as the river discharge above which the flood plain becomes inundated. The concept of bankfull can be difficult to apply, however, since much water enters and exits the flood plain via low areas or discrete openings in the levees (see later text). Many rivers reach bankfull at least annually, but inundate their flood plains less frequently.

River valleys commonly have one or more abandoned flood plains lying on elevated terraces that are normally above the present-day reach of riverine flooding. Such terraces may still contain wetlands and permanent water bodies that reflect their fluvial origin. Wetlands on such terraces may be sustained by groundwater and surface runoff emanating from adjacent uplands in addition to direct precipitation inputs. Terraces containing palm swamps that retain surface water all year are visible to the north of the Madre de Dios River just above its confluence with the Inambari River (Figure 2).

Movements of water and deposition and erosion of sediments sculpt the surface geomorphology of flood plains, particularly during larger flood events. Much attention has been paid to the study of fluvial geomorphology, and the ways in which different hydrogeomorphological regimes produce a myriad of floodplain landforms are well documented. Fluvial deposits can be highly heterogeneous and subject to constant change in active flood plains with high rates of sediment deposition, as for example, in the flood plains close to the Madre de Dios River and on islands in the Inambari River in Figure 2. Fluvial landforms tend to become smoothed out over time, as may be reflected by increased distance from or, in the case of terraces, elevation above the parent river. Erosion of elevated features and infilling of depressions contribute to the long-term homogenization of floodplain surfaces. Yet even in humid tropical climates, traces of the geomorphic features produced by fluvial action may remain visible for tens of thousands of years (e.g., Llanos de Moxos in Figure 4).

Elevated strips of land known as levees often border the river channel and reflect the higher rates of sediment deposition where the river water first decreases in velocity as it exits the channel.
Figure 1  Amazon River (locally known as the Rio Solimões in this reach) and its fringing flood plain above the city of Manaus and the confluence with the Negro River. This image land is about 240 km in width. The Negro River is visible in the upper right. The main river channel contains high inorganic turbidity and clearer waters on the flood plain as well as in the Negro River are dark. The flood plain here shows diverse geomorphic features, including numerous lakes, most conspicuous of which are the dendritic blocked-valley lakes. Image coordinates are 61.20 W, 3.61 S. Image shows Landsat 7 ETM+ data (bands 7, 4, 2) from the Geocover 2000 data set, obtained from NASA World Wind version 1.3.

Figure 2  Madre de Dios River (upper) and its tributary the Inambari River (lower) in the Peruvian Amazon basin. This image land is about 29 km in width. The river channels contain high inorganic turbidity while some oxbows contain clearer water and hence appear darker. Lighter areas are vegetation in early successional stages following fluvial disturbance. The flood plain along the Madre de Dios contains oxbow lakes in various stages of separation and infilling. Much of the Inambari flood plain occurs as islands and bars along the highly braided channel. Between the two rivers is an extensive interfluvial backswamp, and in the upper right the darker areas are palm swamps lying on fluvial terraces. Image coordinates are 69.83 W, 12.70 S. Image shows Landsat 7 ETM+ data (bands 7, 4, 2) from the Geocover 2000 data set, obtained from NASA World Wind version 1.3.

Figure 3  Flood plains of the upper Paraguayan River and tributaries in the central Pantanal (Brazil and Bolivia). This image land is about 200 km in width. The flood plains here include the fringing floodplain of the sinuous Paraguay River (running from north to south), large turbid lakes with permanent connectivity to the river, and seasonally flooded savannas of the Taquari River alluvial fan, which covers the right side of the image. Lower lying areas of the fan are subject to backwater effects from the Paraguay River. Image coordinates are 57.14 W, 18.51 S. Image shows Landsat 7 ETM+ data (bands 7, 4, 2) from the Geocover 2000 data set, obtained from NASA World Wind version 1.3.

Figure 4  Savanna flood plains of the Llanos de Moxos (also spelled Mojos) in the upper Amazon Basin in Bolivia. This image land is about 108 km in width. The meandering Beni River with numerous oxbow lakes flows from south to north. The flood plain here reveals topographic features created by past fluvial activity. Superimposed on this landscape are strikingly regular depressions filled with shallow turbid water; these lakes have been attributed to subsidence patterns reflecting lineaments in the basement rock far below the alluvium. Image coordinates are 67.20 W, 13.99 S. Image shows Landsat 7 ETM+ data (bands 7, 4, 2) from the Geocover 2000 data set, obtained from NASA World Wind version 1.3.
Successively formed, concentric levees and swales may form *meander scrolls*. In some flood plains, these are created by the meandering of smaller channels within the flood plain rather than by the migration of the main channel.

Flood plains can be readily classified based on their geomorphology, and several schemes have been proposed. Fewer classification systems deal specifically with the water bodies on flood plains, although various types of floodplain lakes are included in some geomorphological classifications (see later text). Flood plains can be broadly classified as fringing flood plains (i.e., found along the banks of rivers), coastal deltaic flood plains (formed where rivers meet larger rivers, lakes or the ocean), and internal deltaic flood plains (formed internally where a tributary meets a larger river and is subject to backwater effects). Some river channels, particularly those with braided morphology such as the Inambari River in Figure 2, have much of their flood plain on mid-channel bars and islands, and smaller channels can exhibit lake-like conditions at lower discharge. Wetlands that resemble riverine flood plains but may not be subject to direct inundation by river water include flood plains on terraces, and poorly drained plains adjacent to rivers that tend to become flooded with local runoff during the wet season. Examples of the latter include much of the land in images of the Pantanal (Figure 3) and Llanos de Moxos (Figure 4).

**Hydrology**

By definition, flood plains share the characteristic of being subject to inundation, but key hydrological features of inundation are highly variable. The timing, frequency, and duration of inundation can...
be collectively considered as the hydroperiod. In many kinds of flood plains, there is a range of hydroperiods depending on the land surface elevation with respect to the river. Subtle differences in topography can result in considerable differences in hydroperiod with corresponding variation in ecological characteristics, particularly when the range of inundation depth is relatively small.

River discharge regimes dictate timing and predictability of inundation, while depth and routing of flow within the flood plain reflect its geomorphology and vegetation. Larger river systems tend to have broader and more predictable flood peaks because their large drainage basins integrate the smaller-scale variability of individual precipitation events. Inundation of their flood plains has been termed the flood pulse (see Floodplain Wetlands of Large River Systems). The presence of extensive flood plains or water bodies such as lakes and reservoirs along a large river system also attenuates the flood pulse downstream.

Particularly attenuated and prolonged flood pulses are observed in large, mostly unregulated river systems of South America, where the flood plain typically is inundated once per year, lasting for months and covering much of the flood plain with water to depths up to several meters. Figure 8 shows examples of daily river stage measurements from three large rivers with extensive flood plains: the Orinoco, Amazon, and Paraguay rivers. In the vicinity of these stage measurement sites, the Orinoco has the least flood plain relative to its discharge, while the Paraguay River has the most extensive flood plain (these data come from the southern Pantanal in Brazil: Figure 3). In each case, the inundation lasts for months, with the most protracted inundation in the savanna flood plains of the Pantanal where standing water often persists for more than 6 months of the year. These river systems and their flood plains are so large that the passage of the flood wave through the system takes months, resulting in a time lag between the wet season runoff and the inundation of the flood plain. This time lag reaches 4–6 months in the case of the southern Pantanal.

At the other extreme are flood plains that typically are inundated for only a few days or weeks per year. Examples shown here include the Madre de Dios River (Figures 2 and 9), which drains mountain and lowland landscapes in Peru, and the Kalamazoo River (Figures 6 and 10), which drains a glacial landscape in southern Michigan, USA. In these river systems, the floodplain inundation is seasonal but its timing is not regular, nor is its duration. In a particular year, inundation can occur several times or not at all. The tropical Madre de Dios responds to rain events in the Andes as well as the lowland plains. The stage record for the Madre de Dios River spans only a few years, which is insufficient to characterize its average behavior. The temperate Kalamazoo River responds to rain events but also to snowmelt and rain on snow, which produce a higher proportion of overland runoff in a landscape where liquid precipitation infiltrates the soils during most of the year. Most floods in the Kalamazoo River occur during cooler months (especially March and April) when biological activity is relatively low, and the mean number of days flooded per year is only eight, with substantial interannual variability.
Even brief flooding can be important as a geomorphological force, but from an ecological perspective, brief and unpredictable floods may be viewed as a disturbance that limits the plant and animal life rather than benefits it. In cooler climates, the timing of the inundation is critical as well. Some large boreal/arctic rivers that flow in a northerly direction, such as the Mackenzie River in northwestern Canada...
and the Ob and Yenisei rivers in Siberia, exhibit spectacular flood pulses as the river breaks through ice in the spring.

The most variable river discharge regimes, and hence the most unpredictable flood pulses, occur in certain dryland rivers such as Cooper Creek and the Diamantina River in the endorheic Lake Eyre basin of interior Australia (Figure 5), which tend to flow only when monsoons bring heavy rainfall far into the continent. In these semiarid environments water limits biological activity much of the time, and hence inundation of extensive flood plains and anastomosed channel systems can be important as an ecological process despite its erratic and ephemeral nature. Permanent waters in these systems are known as ‘waterholes’, which are particularly deep channel reaches of restricted length that hold water long after the river has ceased to flow and most of the channel has dried.

The routing of flood waters across flood plains is complex and often changes over the course of the flood event. Commonly, water first enters the flood plain through low breaks in the levees known as crevasse splays, and this water may follow floodplain channels for some distance before spreading out into backswamps or lake basins. Water may also back up through downstream openings, for example, through the lower end of tributaries or oxbow lakes that are connected with the channel. Thus floodplain inundation commences before the levees become submerged. At the highest river stages, most or all levees may be underwater, and sheet flow proceeds generally in the downriver direction.

The water that inundates flood plains does not necessarily originate from overbank flow of the parent river, even though the parent river may control water levels by backwater effects. Flood plains typically show both spatial and temporal variation in water sources. Locally derived water can enter from lateral tributaries, perhaps becoming impounded temporarily by river flood waters, or traveling down the flood plain as deferred flow before mixing with the mainstem (parent) river. In expansive flood plains, the flood waters can be derived from delayed drainage of precipitation falling directly on the flood plain. Groundwater inputs from adjacent uplands also can be important, especially in smaller flood plains or in floodplain wetlands lying close to the upland boundary. Such inputs may maintain a high water table, and thus create wetland conditions for most or all of the year. These distinct sources of flood waters often differ in chemistry and suspended matter, enhancing the biogeochemical and ecological heterogeneity across flood plains.

Freshwater rivers near their confluences with the sea can have flood plains subject to tidal control of water levels, superimposing a short-term cycle of variability on longer-term, discharge-driven flood pulses. Examples include the Amazon and Orinoco deltas, where freshwater discharge is high enough to prevent seawater intrusion yet tidal cycles can be observed for considerable distances upriver. In contrast, rivers with little or no dry-season flow can experience substantial intrusion of seawater in their lower reaches. In such river systems, seemingly modest changes in relative sea level can alter the zone of seawater influence, producing dramatic implications for floodplain ecosystems. Seawater intrusion as a result of erosion of low ridges, possibly instigated by introduced water buffalo, has been documented in northern Australia east of Darwin, where the salinity caused massive changes in vegetation. Sea level rise associated with climate change increasingly will pose a threat to many low-lying floodplain ecosystems that contain freshwater in close proximity to the coastal zone.

Floodplain Lakes

More or less permanently flooded depressions on the flood plain include the backswamps behind the levees and can also include water bodies that are deep and permanent enough to be called floodplain lakes. There is no universal definition that distinguishes a lake from a wetland and usage of ‘lake’ or comparable terms varies regionally. Commonly water bodies that are called lakes have an open-water area for most or all of the year, which distinguishes them from vegetated wetlands. Their open-water areas may not fill with aquatic vegetation even though they can be quite shallow at low water; this may be a result of the changing water levels and low light penetration. Interannual variation in the flood regime can produce striking changes in the proportions of open water and emergent vegetation. Although they are often small in area, floodplain lakes are one of the most abundant types of lakes, particularly in the tropics and arctic where large, unregulated floodplain rivers remain. Very large lakes are associated with some flood plains, such as the Grand Lac on the Mekong River, though these may have a distinct geomorphological origin.

Floodplain lakes are formed by a variety of processes, including the isolation of main channel meanders (oxbows), formation of swales between successive levees, subsidence of alluvial fill, and permanent flooding of incised tributary valleys. Examples of each of these are visible in Figures 1–7. Floodplain lakes may be permanently or seasonally connected to the parent river, and the connections can be broad or quite

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restricted. Lakes that become seasonally isolated from the parent river may become perched at higher elevations than the river level as the river falls, and they may accumulate water of local origin during the phase of isolation from the river, often maintaining a stream that drains to the river.

Lakes typically occupy a minority of floodplain area but this depends on the geological history of the flood plain. Sometimes subsidence or backflooding exceed rates of new alluvial deposition (accretion), producing lakes that cover much of the backswamp areas. Neotectonic processes that cause subsidence, tilting, or uplift of basement rock can create areas of permanent flooding on flood plains.

Most kinds of floodplain lakes are no deeper than the parent river, and they can become very shallow during low water. During periods of isolation or at least minimal through-flow of river water, they can be rich in phytoplankton, although in many cases they become shallow enough that sediments are resuspended by wind-induced turbulence and inorganic turbidity greatly restricts underwater light availability (e.g., the large oval lakes in the Llanos de Moxos: Figure 4). During inundation they receive through-flowing river water and this may drastically reduce the water residence time to the point where plankton growth is suppressed by flushing.

Remote Sensing of Flood Plains

Delineation of floodplain boundaries by remote sensing can be challenging due to temporal variability in the extent of inundation and the difficulty of detecting standing water beneath vegetation canopies. In some humid tropical flood plains, the nearly perpetual cloud cover can also impede optical remote sensing systems. The difficulty of observing inundation dynamics by remote sensing has led investigators to rely more on vegetation and geomorphological features to delineate flood plains, and these features usually provide a reasonable indication of the overall floodplain extent and the boundaries between flood plains and upland ecosystems. At coarse spatial scales and in remote regions of the world, new remotely sensed, elevation data (e.g., the Shuttle Radar Topography Mission) are proving useful as well because they reveal the extent of relatively level terrain along major rivers.

Remote sensing of flood regimes can provide information for hydrological modeling and ecological and biogeochemical investigations in flood plains. Traditional optical remote sensing, including aerial photography for limited areas and Landsat satellite imagery for extensive areas, can provide snapshots of flood extent, but often lacks temporal resolution and may be inadequate for the reasons mentioned above. Relatively new microwave technologies such as radar can be better for hydrological dynamics because of their all-weather capability (i.e., they are less impeded by cloud cover) and their ability to penetrate vegetation to at least some degree. Several microwave systems are currently deployed on orbiting satellites and data from these sensors have provided new insights into floodplain hydrology. New image analysis approaches that combine multiple types of imagery are especially promising for remote sensing of flood plains.

Functions of Flood plains

The permanent and temporary aquatic environments of flood plains are locations for a number of important ecosystem processes, or functions, which provide values and services to people. Flood plains tend to be highly productive ecosystems and have long been utilized for production of food and fiber and harvest of wild plants and animals. Perhaps the greatest contrast in productivity between uplands and flood plains occurs in dryland regions, but even in humid climates the flood plain is often desirable for farming and livestock production.

The temporary residence of water on flood plains is an important hydrological function because it delays the passage of flood waters through the fluvial system. This delay tends to attenuate the flood peak downriver, reducing peak water levels, which often is advantageous to riverside communities and agricultural activities. Passage of river water through flood plains can significantly enhance evapotranspirative losses, which in dry regions may be viewed as negative, but also may increase groundwater recharge. Some flood plains overlie extensive alluvial aquifers and these can provide a readily accessible water supply that is recharged by seasonal flood pulses.

Passage of river water through floodplain environments changes its content of dissolved and suspended matter, which can affect the composition of riverine exports. Suspended sediments tend to show net loss by deposition, whereas nutrients may show net retention or transformations. Concentrations of certain pollutants, particularly those associated with particulate material (e.g., trace metals) as well as labile nutrients (e.g., nitrate), are often greatly reduced in water passing through flood plains. High rates of primary production can result in net export of organic matter back to the river, although it is unclear.
whether flood plains are a net source or sink for riverine organic carbon.

Under certain circumstances, water quality can be diminished by passage through flood plains. Strong oxygen depletion upon initial inundation of some tropical flood plains is known to result in fish kills (e.g., the Pantanal in Brazil). In coastal plains of tropical Australia, initial contact of flood waters with acid sulfate soils can cause marked decreases in pH and result in metal toxicity for fishes. Such leaching effects usually diminish as the flood plain is increasingly flushed by flood waters.

Extensive flood plains can be important as sources of greenhouse gases to the atmosphere. It remains uncertain whether flood plains tend to be net sources of sinks of carbon dioxide, but like other wetlands they certainly tend to be net sources of methane while they are wet, and they may be important sources of nitrous oxide as well, particularly in regions with nitrogen pollution. Tropical flood plains are a globally significant source of methane emission to the atmosphere because of their extensive area and high biological activity. In general methane emission rates are proportional to primary productivity in wetlands, and this presumably extends to flood plains as well.

In rivers with extensive flood plains that are inundated for relatively long periods, much of the primary and secondary production in the overall river–flood plain system can occur in the flood plains. The Flood Pulse Concept articulates how such flood plains serve as the locus of biological production, supporting rich aquatic and terrestrial biodiversity including economically and culturally valuable fisheries (refer to ‘see also’ section).

**Human Modification of Floodplain Hydrology**

The age-old proclivity of humans to control river systems, combined with our ever-increasing technological ability to do so, has made flood plains one of the most altered aquatic ecosystems. River regulation, mainly through construction of dams, has strongly impacted flood regimes of rivers across all spatial scales, and even many of the largest rivers of the world have been regulated to some degree.

Impoundments tend to create permanently flooded reservoirs in place of seasonally flooded lands (Figure 6), and in many cases, they alter the discharge regime and often the water quality and temperature well downstream. They can trap a large fraction of the suspended sediment load, leading to geomorphological destabilization of the river–flood plain system downriver of the dam. Dams operated for hydroelectric generation may impose highly unnatural, short-term fluctuations in water levels, while those operated primarily for agricultural irrigation tend to change the seasonality of river flow in addition to removing water from the system.

Modification of river channels to facilitate navigation usually impacts flood plains by altering the relation between water levels and discharge. Removal of natural barriers to navigation can entail dredging, channel straightening, and excavation of rock outcrops. All of these measures tend to enhance flow conveyance and diminish the backwater effect that produces overbank flooding. Construction of navigation locks is akin to damming rivers. Low-head navigation dams that allow passage of flood waters, such as those on the upper Mississippi River (USA), are less damaging but still create extensive permanently impounded areas at low water levels.

Flood plains have often been isolated from their parent rivers by construction of dikes, commonly with the goal of farming the land (see Mississippi River example in Figure 7). Such land can be highly productive but may require costly measures to remove or control water, and over time land subsidence, loss of fertility, and occasional incursion of flood waters can detract from its sustainability. Nonetheless, agriculture on converted flood plains has played an important role in many societies and continues to be significant throughout the world. In some regions flood plains have been extensively mined for clay, sand or gravel, gold, or diamonds, a provisioning service that is sustainable only if subsequent floods replenish the material that is removed.

Aquatic ecosystems on flood plains are also impacted by urban and agricultural development in the upland watershed, which results in alterations to the flow regime and water quality of the parent rivers. Runoff is intensified by impervious surfaces and stormwater runoff drainage in built areas, and by land clearing and wetland drainage for agriculture. Nutrient loading to rivers and their flood plains increases with development, although the floodplain biota can have a large capacity for nutrient uptake and retention, and the effects of intact flood plains on water quality can be viewed as a valuable ecosystem service.

See also: Ecology of Wetlands; Floods; Flow in Wetlands and Macrophyte Beds; Fluvial Export; Fluvial Transport of Suspended Solids; Geomorphology of Streams and Rivers; Global Distribution of Wetlands; Riparian Zones; South America; Streams and Rivers as Ecosystems; Streams; The Surface Mixed Layer in Lakes and Reservoirs; Tidal Freshwater Wetlands; Wetlands of Large Rivers: Floodplains.
Further Reading


