LEVEE MODIFICATION AND REMOVAL

1 DESCRIPTION OF TECHNIQUE

This technique describes the full or partial removal, breaching, lowering, and/or relocation of artificial stream and tidal levees for the purpose of habitat restoration. Levee Modification and Removal serves many purposes including but not limited to: habitat restoration, erosion reduction, water quality improvements, groundwater recharge, restoring wildlife migration corridors, and reduction of flood hazard risks. Levees directly affect floodplain extent and connectivity with the stream channel, which affects available habitat and complexity. Undeveloped, natural floodplains provide stream energy dissipation and flood storage by allowing flood flows to dissipate, thus reducing velocities and providing areas for organic and inorganic sediment deposition. These low velocity areas provide refuge areas for aquatic species during floods and are excellent habitat for a wide variety of species. From a restoration perspective, it is preferable to have an entire levee removed, but where complete removal is not feasible, the use of setback levees or carefully placed breaches can provide excellent restoration opportunities.

Because most levee removal or setback projects will result in some changes to channel and floodplain processes, a thorough understanding of fluvial geomorphology is essential. Refer to the *Fluvial Geomorphology* appendix and to Stream Habitat Restoration Guidelines *Chapter 2: Stream Processes and Habitat*, for further discussion of channel stability and equilibrium.

1.1 Background

The United States has over 25,000 miles of levees, dikes, embankments, and floodwalls, but despite this relatively high level of "protection", flood losses continue to increase. The use of levees for flood protection generally results in, and even encourages, increased development of floodplain areas because of the public perception that the area will not be flooded. For instance, Pierce County, Washington has been identified by the National Wildlife Federation as one of the top 300 locations within the United States where there are repeated flood damages of individual properties in excess of $1,000. In fact, repetitive loss to properties in Pierce County accounted for only 2% of all National Floodplain Insurance Program (NFIP) claims, but sustained 25% of all NFIP losses, and received 40% of all NFIP payments[1]. Often the loss in floodplain storage from dikes results in increased flood water elevations, and thus increased flooding, elsewhere in the watershed.

Levees or dikes are defined as artificial embankments, usually of random earth fill, built along the bank of a watercourse or an arm of the sea and designed to protect land from inundation or to confine streamflow to its floodway[2]. Accordingly, the Natural Resources Conservation Service (NRCS) uses three classes of dikes designated by the type of land use they are protecting. Class I dikes are constructed in areas where levee failure may cause loss of life or serious damage to homes, businesses, or transportation networks. Class II dikes protect areas where failure may result in damage to isolated structures, some infrastructure, and high value crops. Class III dikes are constructed in rural areas and protect lower value agricultural land. Each of these dikes has specific design criteria depending upon the level of protection provided by the levee[3]. There are various types of levees used for flood protection, which include:

1. Lateral levees – built adjacent to a stream channel to confine flows within the active channel. Often used in conjunction with channelization and/or dredging projects. Generally requires a high structure to reduce flooding due to the limited cross-sectional area. Revetments and other types of bank armoring are common with this type of structure.
2. Setback levees – generally parallel to the stream but placed far enough from the active channel to allow overbank flooding and some natural floodplain function. The degree of setback is variable, however, narrow setbacks may result in erosion on the surface of the newly established floodplain due to high flow velocities. Structures are generally lower than lateral levees and require less maintenance.
3. Perimeter levees – used primarily to protect individual structures, groups of structures, and wells. Often called "ring dikes", these levees protect small areas from flooding rather than confining flood flows within the stream channel or floodway. Levees are generally broad in cross-section to accommodate equipment and vehicle access and other land uses.
4. Cross-floodplain levees – generally perpendicular to the stream and used to redirect flood flows back into the active channel or floodway. They allow floodplain storage of water but no flow parallel to the stream. For instance, road fill across floodplains can inadvertently function like cross-floodplain levees by creating constrictions that cause localized scour, channel down-cutting, and backwater conditions upstream. Cross-floodplain levees may be required at the upstream and downstream limits of a levee removal or setback project, so that adjacent land outside of the project area is not flooded.
5. Tidal levees – used to protect land specifically from high tide and saline water. This results in the conversion of tidal marshes into other habitat types. Tide gates are often used in conjunction with tidal levees. Fresh water can be trapped on the landward side of these levees increasing the salinity gradient at the tide gate, which may impact species that migrate through the freshwater/saltwater interface.
6. Deflecting levees – the objective of deflecting levees is for "river training" rather than flood protection. Structures are used to control flow direction during floods. Deflecting levees need not be continuous.

In the early 1900s, many lateral and tidal levees were constructed or authorized by the U.S. Army Corps of Engineers (Corps), which is consistent with other Corps dredging and navigation projects during this period. For example, in a delta area a typical Corps project would focus the river's flow into one main channel to establish a navigable river channel. Many of the sub-channels in a river's delta would be closed and training dikes would be installed to guide the channel, whereupon dredging would ensue to establish the channel to the appropriate navigation depth. Dredged materials would typically be side cast for use in construction of the adjacent dikes.

1.2 Geomorphic Consequences of Levees

Natural levees are found along the margins of many alluvial stream channels and are formed by the deposition of the coarser part of the sediment load when stream flows exceed channel capacity and the water flows onto the floodplain[4]. Artificial levees, however, are designed to contain high flows within a specified area and have been used universally throughout the world for flood protection along stream systems and in tidally influenced areas. While initially effective in reducing inundation, levees have numerous drawbacks.

Levees constrain stream flow to a smaller cross-sectional area, thus velocity and stream power are higher after levee construction for similar discharges. Increased stream power results in more pronounced erosion and depositional sequences, often causing channel incision and over-steepened streambanks. In turn, channel incision can lead to accelerated bank erosion and the introduction of additional sediment into the stream system from the mechanical failure of over-steepened banks. Additionally, deepening of the channel bed reduces connectivity between the stream and the floodplain, thus confining more flow to the primary channel. If the stream bed is armored, or a resistant layer is encountered, the channel may preferentially erode its streambanks.

Vegetation is often removed from the levees to preserve structural integrity and is also removed from areas within the levees, referred to as the "floodway", in order to decrease roughness, increase velocities, and hence lower flood stages. This reduction in energy dissipation further increases stream power and flow velocities, reinforcing the processes responsible for channel boundary erosion and channel incision.

The loss of available floodplain reduces areas in which channels respond to changes in watershed inputs (water, sediment, wood). By reducing sediment storage adjacent to the channel (in the floodplain), deposition of sediment occurs within the channel during low flow periods, potentially resulting in aggradation. Sediment that would be otherwise stored in the floodplain or along the channel margin is routed downstream, increasing the sediment load and triggering additional aggradation. Accordingly, the channel responds to aggradation through channel widening (braiding), lateral migration (if banks are composed of erodible material), or avulsion (a partial or complete shift in the channel location). In extreme examples, the channel bottom can aggrade so severely that it becomes perched above the surrounding landscape, in essence flowing at an elevation higher than its surrounding floodplain. An example of this is the Skokomish River in Mason County, Washington, that drains into Hood Canal; another is the lower Dungeness River that flows into the Strait of Juan de Fuca. In contrast, during high flows stream power is magnified within the constricted channel (as described above) and much of the sediment stored in-channel can be rapidly mobilized. This results in a stream system that has amplified cycles of erosion and deposition. This increase in depth of bed scour allows more frequent adjustment of channel form and may undermine bridges and other channel-spanning infrastructure and has biological consequences (e.g., redd scour) that are described below.

2 PHYSICAL AND BIOLOGICAL EFFECTS

Levee removal can potentially restore a more stable cycle of erosion and deposition by allowing the channel to access its floodplain. In doing so, the channel can dissipate stream power from overbank inundation and deposition and adjust to variations in watershed inputs (water, sediment, wood) from channel migration (lateral migration and avulsion). By restoring floodplain functions and channel processes, levee removal has many potential physical and biological benefits. In contrast, levee removal may also cause further instability if the channel has adjusted to the presence of the levee. In summary, the potential physical and biological effects of levee removal include:

Potential physical effects:

- Change in energy distribution within the channel (usually decrease) and on the floodplain/floodway (usually increase), which more closely mimics natural conditions.
- Reduction of water surface elevation at the site and upstream during floods.
- Increased overbank flow resulting in greater potential for increases in groundwater recharge in the floodplain.
- Reduced flood potential to downstream areas by increasing storage of flood water.
- Attenuation of sediment transport downstream by providing sediment storage.
- Greater channel complexity and/or increased shoreline length.
- Increased floodplain flows and thus floodplain channels, diversity and interaction with the active channel.
- Stabilization of the channel reach from chronic erosion or instability due to sediment deposition.
- Short-term and/or chronic instability if the channel has evolved to the hydraulic condition of the presence of the levee.
- Changes in channel geometry as the newly unconfined channel evolves to its new hydrologic situation.
- Restoration of estuarine functions of temperature, tidal currents, and salinity in the case of tidal levee removal.
- Increased habitat abundance from distributary channels, which increase in size after tidal flows are allowed to inundate on a twice daily basis and scour.
- Increased width of the riparian corridor.

Potential biological effects:

- Increased riparian function including:
  - increased shade and hence moderated water temperatures and microclimate,
  - increased abundance and retention of wood,
  - increased organic material supply,
  - water quality improvement,
  - filtering of sediment and nutrient inputs,
  - nutrient cycling,
  - seed dispersal, and
  - wider, more effective migration corridor for terrestrial species.
- Restoration of flood-flow refuge for aquatic species.
- Reduction of fine sediment in-channel and downstream, including estuary filling by providing low energy, overbank storage areas for fines.
- Restoration of fish and wildlife access into tributaries, floodplain habitats (side channels,

off-channel ponds and wetlands) main channels, estuaries or ocean by reestablishing historic channels.
- Restoration of saline-dependent plant species and thus increased drainage (tidal levees).
- Increased primary productivity.
- Restoration of estuarine food production (tidal levees).
- Restoration of an estuarine transition zone (tidal currents, temperature, salinity) for species migrating through the tidal zone.
- Shift in vegetative community composition and distribution.
- Shift in wildlife species composition and distribution.

An example of a biologic effect is the existing dike structures in the Deepwater Slough area of the Skagit River delta that create a system of disconnected habitats. The lands behind the existing dikes provide habitat for a variety of invertebrate, amphibian, and plant species. These habitats produce an important food source to a variety of predators; however, the great majority of the biomass and organic nutrients inside of the dikes cannot be transported out of the area due to the blockages. With the dikes in place, there is no hydraulic connectivity between these habitats and the river and estuarine environment. It is hypothesized that the lack of biomass and nutrient transport to the river and estuary has become an ecosystem function-limiting factor in this system.

3 Application of Technique

Levee removal or setback applies to all stream systems that have artificial levees in place, but is most beneficial in streams that are not incised and are still capable of accessing their historic floodplains at relatively frequent flows (during the 2 to 5-year flood events). Channels that are incised require careful examination to determine whether trends in down cutting are on-going or have reached equilibrium. Accordingly, implementation of levee removal or setback in incised channels is augmented with in-channel grade control in order to reverse the incision process.

Focus should be placed on streams where infrastructure and floodplain development is minimal, but may increase in the future; once floodplains are developed, modification and removal opportunities become limited and more expensive. Areas of specific interest include undeveloped lands, agricultural areas, public lands, and parks; these areas favor restoration of natural floodplain vegetation, flood channels, and active side channels. By restoring floodplain functions and processes, Levee Modification and Removal can be used in conjunction with many other techniques including but not limited to: Channel Modification, Log Jams, Bank Protection, Land Preservation and Buy Back, Riparian Restoration and Management, and Side Channel Habitats. Accordingly, floodplain restoration work should often begin prior to modification or removal as long as access is retained for actual construction work.

4 Risk and Uncertainty

Flood damage typically results from levee failure rather than levee overtopping. If flood stage exceeds levee height, then overtopping is imminent. The overtopping may cause levee failure by cutting back through the levee at the point where it is overtopped, however, it is much more common for a failure to occur before overtopping. Because of the hydraulic pressure gradient (the difference in water surface elevations on either side of the levee), seepage occurs through the levee and discharges on the "dry" side. This increases overall pore pressure, which reduces shear strength in cohesive materials. Increased velocity can cause piping, or excavation of material from the inside of the levee, which leads to failure. Once a levee is breached, water shoots through the opening at very high velocities, entraining material within its path. The area behind the levee becomes inundated and, depending upon the local topography and the levee system, may not be able to naturally drain.

The Levee Modification and Removal technique has a low technical uncertainty, assuming the analyst completes the appropriate analysis and modeling. Overall, the analyst should have access to hydraulic and sediment transport modeling software that allows quantitative analysis of the risk incurred by levee modification or removal. Accordingly, risk analysis must include:

1. Assessment of changes in channel stability resulting from levee removal or setback.
2. Assessment of the hydraulic effects on upstream and downstream reaches and on the floodplain within the project area.
3. Assessment of changes to flood hazards.
4. Assessment of stream channel response within the project area.

Stream, estuary, and tidal system adjustments to levees may be complete or on-going, and they must be addressed before levee modification is undertaken. For instance, the cross-sectional geometry or longitudinal profile of a stream channel may be significantly altered due to a levee on one or both banks. Therefore, a geomorphic analysis is required to determine potential stream adjustments after the levee is removed. In some situations, it may be necessary to restore some floodplain functions, such as topography, roughness, and structure, before a levee is removed.

The primary hydraulic effect of levee removal is restoration of overbank flows. Accordingly, the designer should estimate the effects of levee removal in situations where the channel has evolved to the presence of the levee. Levee removal may actually decrease channel capacity in streams that have aggraded in response to the constraining effect of the levees. In some cases there may be no channel capacity at all. In these situations, without mature flow channels in the floodplain, this situation can result in years of chaotic channel evolution as it tries to develop a suitable alignment, shape, and slope.

Additionally, hydraulic effects of levee removal or setback include changes in channel and floodplain roughness and a potential change in channel length and slope, which in turn affect velocity and shear stress. Generally, velocity and shear stress will decrease causing a loss in sediment transport capability through the levee removal reach. For instance, the reach upstream of a levee removal project may experience increased velocity and shear stress as the backwater of the levee during flood events is eliminated. Sediment deposition on the floodplain should be expected. Hydraulic models are available to help predict these changes. Many analytical tools are available for flood routing (HEC-RAS) as well as standard designs for levee construction from entities such as the US Army Corps of Engineers and the Natural Resources Conservation Service. Likewise, sediment transport models (HEC-6 and GSTARS) are helpful for addressing issues associated with sediment deposition within the project area and in the upstream reach, but should be used with caution as sediment transport modeling is an inexact science with large margins of error.

4.1 Risk to habitat

Risk to habitat is generally low for levee modification or removal. Primary risks include longer and more frequent inundation, which may result in changes to vegetative communities and hence animal assemblages. Localized scour and increased velocities may impact existing habitat. Most habitat losses will be replaced by increased habitat in other parts of the floodplain and a significant increase in habitat complexity.

The greatest risks to habitat may occur while attempting to restore floodplain topography; excavation of floodplain features can result in fish stranding after high flows. Likewise, proliferation of exotic species, both plant and animal, may be of concern during the initial years of reestablishment. If a levee setback is not extensive enough, there may be scouring flows over the floodplain essentially resulting in an over-widened channel. Hence, vegetative success would be low and the area would have minimal value for aquatic and terrestrial species.

Another risk to habitat is land subsidence due to disconnection of the floodplain from the source of sediment, dewatering, compaction, and peat decomposition. When reconnecting a subsided floodplain to an active channel, the surface of the floodplain may be too low resulting in constant inundation. If the subsidence is significant, the channel may avulse through the floodplain. Eventually the floodplain will regain its former elevation if sediment is available, but the initial plant community may be representative of a much lower elevation than expected.

4.2 Risk to infrastructure and property

Risk to infrastructure can be very high depending on site conditions. For levee removal, flooding and channel erosion may pose a significant threat to infrastructure and buildings. Geomorphic and hydraulic evaluations of flood elevations, inundation periods, and potential patterns of channel migration are essential for evaluating risk. There is a lower risk to infrastructure and property with levee setback if the flood capacity is maintained, except for the property on the streamside of the levee. Levee setback can actually improve flood protection for adjacent infrastructure and property because the flood capacity is often increased due to a greater cross-sectional area and storage volume for the channel and floodplain.

Another aspect to infrastructure and property risk is increased scour and bank erosion within the project area. If scour is significant, the channel could avulse to a new location within the floodplain. Scour is a concern because new areas will be opened to flow and others areas will be more prone to erosion immediately after the construction (or deconstruction) phase. Energy dissipation and bank protection may be necessary in critical areas where scour is not acceptable. Scour analysis models are available to help quantify the risks of erosion and avulsion. See the Integrated Streambank Protection Guidelines[5], for information regarding streambank protection and avulsion risk reduction.

Flood risk can be evaluated using available models, which calculate backwater curves during flood events (HEC-RAS). Flood risk is usually decreased for adjacent areas by the removal or setback of a levee except for the area directly impacted by the activity. Long-term flood risk is generally reduced for all areas if the floodplain and channel are returned to a condition in which overbank flows are more predictable and the channel and flood stages are not super-elevated above the surrounding floodplain by being confined by levees.

Local zoning may need to redefine the extent of the 100-year floodplain to better represent the areas at risk of inundation.

4.3 Risk to public safety

Risk to public safety can be either increased or decreased depending on the project. Because flood elevations are actually lower with levee removal or setback, and risk of levee breaching is reduced, public safety is enhanced. If, however, proper analysis of flood stage and routing has not been completed, inadvertent flooding in previously non-flooded areas could decrease public safety. Areas that have historically been protected by levees may be perceived as "safe" by the public, even during large flood events. Public education and awareness is a critical component to projects that change flooding regimes along streams.

5 METHODS AND DESIGN

Levee modification and removal generally entails a high level planning and design. Projects may require several years of coordination and planning to obtain environmental clearances, landowner permission, easements, and adequate analyses and designs before they are ready for implementation. Even the implementation stage could be phased over several years depending upon the scale of the project. Basic assessment and data needs are discussed below, although individual project needs may vary considerably.

5.1 Data and Assessment Requirements

Reach-scale geomorphic assessments are essential for quantifying the hydraulic and geomorphic effects of modifying or removing levees (refer to Stream Habitat Restoration Guidelines *Chapter 3: Stream Habitat Assessment*). Projects implemented at the reach scale are preferred over site-specific projects because they restore more floodplain functions and amplify beneficial effects. They also potentially reduce the cost per acre because cross-floodplain levees are not required to protect adjacent lands. Accordingly, watershed-level assessments are necessary at some level to account for potential actions and effects to the reach in question.

In evaluating levee modification or removal, determining the relative elevation of a channel or estuary to the floodplain surface is a critical component for project feasibility and planning. For instance, areas protected by levees may subside due to the disconnection of the contributing water body, which results in significant decreases in organic and inorganic sediment deposits, increases in soil compaction, and decomposition of organic materials in the soil. Because subsidence in conjunction with instream deposition may result in a perched channel condition, modification or removal of a levee will likely require an analysis by a registered professional engineer to determine the effects on flood elevations, scour and deposition, and impacts to adjacent lands. Geomorphic and hydrologic analyses are essential for evaluating how the channel has evolved to an artificial condition in response to the levee confinement.

In a second example, many levees provide bank stabilization due to artificial armoring of the levee bank, therefore removal of the levee results in removal of the armoring, and a potential increase in erosion. Accordingly, short-term bank protection may be necessary to stabilize bare, erodible banks until native vegetation has become effective. See the Integrated Streambank Protection Guidelines for further guidance.

In summary, the degree of risk and uncertainty dictates the amount of data collection and assessment required for a given project. If possible, compare current channel geometry to pre-levee geometry to assess the extent of channel change, and determine the rate of change, in order to predict the rates of future channel change. Aerial photography is an excellent tool for determining the rates of change for channel planform, but is not helpful for channel geometry changes, hence the need for cross-section data over time. For most levee modification or removal projects, the following data collection and assessments are required.

Data Needs:

- Hydrology (high flow frequency, magnitude, timing, and duration) for analysis of flood and sediment effects.
- Topographic survey with cross-sections (including in-channel, levee, floodplain, and surrounding area which will potentially be impacted) for analysis of flood effects and for potential realignment design.
- Section characteristics sufficient for backwater hydraulic modeling including expected in-channel debris, channel variability, and bank and floodplain vegetation type and abundance.
- Land use, property ownership, and infrastructure at risk for analysis of flood risks, to help minimize risks, and to investigate channel alignment alternatives. Levees are structures that may have specific legal constraints due to flood hazards and flood elevations as mapped by the Federal Emergency Management Agency (FEMA). Determining who owns and maintains the levee is critical before an analysis for modification or removal is undertaken. Even if levees are located on private land, the jurisdiction may fall to the US Army Corps of Engineers, local flood control district, or other entity. Modification or removal of small levee systems owned and built by a private landowner may be easier to accomplish, although impacts to adjacent lands should still be investigated. This becomes more feasible if a levee has breached during a high flow event, and the breach is not repaired.
- Channel bed and bank materials for sediment and scour analyses.
- Floodplain characteristics (including soils, potential flow paths, vegetation, roughness, infrastructure and natural constraints to channel migration).
- Sediment load and sediment transport characteristics.
- Channel and floodplain cross-sections and floodplain characteristics of a reference channel may be needed if those parameters are not defined at the project site in post-project condition.

Assessment:

- Assess habitat benefit of specific levee modification or removal in terms of specific biological effects that were generally described previously.
- Hydraulic modeling of impacts to river stage during high flow.
- Sediment transport analysis.
- Scour analysis, especially for levee breach and setback options.
- Risk to infrastructure (i.e., roads and bridges) located upstream and downstream.
- For levee removal, some form of channel migration hazard study may be needed for establishing potential migration risk (low, medium, high) (this is more likely an issue on medium and large-sized rivers).
- Evaluate upstream and downstream effects of levee removal/setback including flood and sediment storage and rerouting through the floodplain and channel profile changes upstream.
- Evaluate how the stream has responded to the levee over time, and possible permanent or temporary secondary restoration activities needed, such as grade control, realignment of channel, and/or revegetation efforts.
- Assess value of various levels of setback. Setback design is often ultimately based on the longevity of sediment storage and channel migration zone rather than quantifiable hydraulic changes to the channel.
- Assess trends in channel movement, specifically channel incision – has the channel achieved a state of quasi-equilibrium, or is it still incising?

The following is a sample design process, which covers the main components required for a levee modification or removal project.

Design process:

1. Define goals and objectives.
2. Develop topographic maps and hydraulic model of existing condition.
3. Model various scenarios of removal, setback, and breaching including setback distances in terms of sediment storage, scour, flood storage, flood stage, and channel migration.
4. Engineering design for setback levee.
5. Engineering design for any accommodation of levee modification such as channel alignment, grade control, floodplain restoration, and protection of setback levee and/or infrastructure.
6. Bank design as necessary to repair disturbance to banks.
7. Design drawings, specifications, and contracting information.

5.2 Channel and Floodplain Modifications

Levee modification or setback projects are intrinsically linked to a linear system that transfers energy and mass. It is essential that a levee project be evaluated within the context of this system and not extracted into a hypothetical closed system with known variables and assured outcomes. The scope of a project should be expanded well beyond the footprint of the project when evaluating impacts, benefits, and risks.

With this more global scale in mind, it may be necessary to modify the channel upstream and/or downstream from the project site and the floodplain behind the levee before the levee modification is constructed to reduce negative impacts such as erosion or avulsion. Specific guidance on modifying in-channel characteristics is provided in the *Channel Modification* Technique.

An early project task includes an assessment of floodplain characteristics, which is essential for evaluating the vegetative, structural and topographical changes that are needed to complete the project. For example, converting an agricultural field to a floodplain may require placing wood or planting and managing floodplain vegetation for some period of time in order to provide functional roughness components prior to levee modification or removal. Accordingly, a floodplain assessment and a channel assessment are critical for evaluating the risk of avulsion. For instance, if flow velocities over the floodplain are high enough to entrain sediment, and there is low roughness due to prior land management activities, then the potential for channel avulsion is high. Unless avulsion is an acceptable and anticipated channel process, precautions may be required to manage for this potential. For example, regulating flow at levee breaches may reduce the risk of avulsion and contain most of the flow in the primary channel; depending on the project, log or dense plantings of vegetation may adequately meter flow into the floodplain. In evaluating avulsion hazards and flow regulation, the elevation of the breach is critical in establishing when the floodplain will become active. In some cases, it may be desirable to leave a low levee along the channel in order to mimic natural levees.

Additionally, restoring floodplain topography is often a high priority in restoration projects. However, this may not be necessary or even desirable in some situations. Florsheim and Mount[6] documented floodplain topography changes after intentional levee breaches along the Lower Cosumnes River in California, and found that excavation of floodplain ponds and other depressional features actually trap incoming sediment and retard the development of floodplain topography.

5.3 Levee Removal

Levee removal has a number of considerations that relate to the excavation and removal of the structure itself. Unlike a levee breach, a levee removal project must consider the amount of sediment to be removed and the distance to a disposal site. Implementing a levee removal project includes:

- Establishing entry and exit points. Entry and exit points are often on the levee itself, given the surrounding land may remain saturated for extended periods. This may require clearing vegetation for access and establishing a turnaround area.
- Determining haul road locations,
- Removing and/or trimming vegetation,
- Excavating and removing material. Excavation and hauling costs will comprise the majority of the budget. The approximate volume of a levee is easily calculated, which allows for a relatively accurate estimate of removal costs since excavation costs per cubic yard and hauling distances will be a fixed value.

- Ripping the footprint area of the levee in compacted areas. Levees built to an engineering standard were compacted during construction. Consequently, this will require ripping the subsoil at the final grade to reduce compaction and allow for vegetative reestablishment. Topsoil should be stockpiled for later use on these mineral soil areas.
- Recontouring of the site.
- Revegetating the site.

Given the cost of removal and disposal of levee materials, complete levee removal is most feasible in areas that have relatively low and/or short levees denuded of vegetation. For highly sensitive areas, or areas that have very mature vegetation, consider either remnant islands of vegetation or carefully placed breaches as opposed to full levee removal. Leaving islands of mature vegetation intact will provide a seed source and some habitat during the reestablishment period. Natural channel avulsions often leave higher upland areas within an active floodplain.

5.4 Levee Setback

Levee setback is an excellent option for areas where levee overtopping is common (such as along coastal streams), and where significant land use changes are unlikely to occur. Levee setback requires the same construction components as removal, in addition to rebuilding the levee itself. Accordingly, this requires separating the organics from the excavated levee material if it will be used in the new setback levee. A temporary storage area to stockpile soil material will also be required until levee construction is complete. A qualified engineer can help with logistics and plans for levee removal and can also develop design guidance for the new levee.

One of the great advantages of a levee setback is that it allows for seasonal use of land within the newly established floodway, and greater flood protection. Generally, greater beneficial impacts are associated with wider setbacks (discussed in previous sections). While setback distances will vary greatly and are often dictated by landowners and land managers, to restore the majority of floodplain functions, the minimum setback distance should be 7 to 10 channel widths[7]. However, setback distances do not need to be equal on both sides of the stream or longitudinally along the stream. At a minimum, the setback levees should be on the edge or outside of the meander belt width. Since it is unlikely that a levee would be setback on two separate occasions in the same location, maximum setbacks should be obtained on each and every project. Setbacks become like default easements since flooding is allowed which will generally curtail development.

5.5 Levee Breach

Levee removal and setback projects can be unfeasible if they are not easily accessible by large equipment, if vegetation is mature and well-established, or if the cost is prohibitively high. In these scenarios, levee breaching may be an excellent option. On a local scale, and generally for individual projects, levee breaches can be used as a low cost alternative to complete levee removal. Levee breaches still allow for some level of inundation of the floodplain, floodwater storage, sediment deposition, and refuge areas for terrestrial and aquatic species, although not to the same extent as removal or setback.

An analysis for levee breaches will be similar for removal or setback, but on a more site-specific scale. Localized scour is of greater concern because of the concentrated energy of the flow at the breaches. The size and location of breaches should be carefully evaluated to minimize the risk of scour due to flow constriction and channel avulsion in areas where levees are used as river training structures. It is fairly easy to calculate breach size using expected volumes and critical flow velocities; if breaches are too narrow, flows are constricted and may result in bed scour and floodplain channel development, which could lead to avulsion. Narrow constrictions may also limit fish passage. Where scour is anticipated, it may be necessary to add energy dissipation in the form of vegetation or large wood, which can be incorporated into the design to dissipate energy and reduce flow velocities near the breach area. If a single breach area cannot be adequately enlarged, consider adding multiple breaches to reduce shear stress and flow velocities; multiple breaches will also help reduce the risk of channel avulsion and will provide alternative channels if one of the breaches plugs with wood or becomes inoperative.

Since many levees were also designed to provide river training, there may be a need to maintain some river training function of the levees. In this situation, breaches can be placed in areas that will allow backwatering of the floodplain during high flow events without allowing channelized flow access to the historic floodplain. For backwater breaches, generally the lower half of the inside of a meander bend, where natural deposition is expected, is a good place for the breach, which allows for some floodplain function, flood storage, and reduces hydraulic gradient between the floodplain and channel. Another benefit for landowners with land in some type of production is the ability for the land to naturally drain after a flood event. Many areas that are leveed become large stagnant pools of water after floods overtop the levees and there is no method for drainage.

In some circumstances, open breaches are not acceptable, especially in areas where an access road is located on the top of the levee. Culverts or bridges can be placed through the levees to allow some connectivity to the historic floodplain while maintaining the access road. While this is not the preferred alternative, it can still have beneficial effects for aquatic and terrestrial habitat. Maintenance for culverts and bridges should be factored into the overall cost of the project.

No matter what type of breach is used, all breaches should be placed preferentially in low areas or in areas where channel remnants still exist. Natural breaches, as a result of flood events, provide excellent opportunities to increase breach size or to place culverts or bridges. These natural breaches also work well with an adaptive management approach where new breaches are not repaired, but are incorporated into an existing project. It is even possible to clear some vegetation to help set the stage for a natural breach without actually using equipment; while the certainty is much lower, so is the cost.

6 PERMITTING

Various permits will be required at the local, state, and federal levels depending upon the location of the existing levee system and who owns and/or maintains the levee. Refer to the *Typical Permits Required for Work in and Around Water a*ppendix for further information. Counties generally require grading permits and also have regulations regarding work in floodplains (check with the appropriate county and/or city for requirements). Any changes to flood elevations will require additional permitting from the state and county. Construction related permits, including sediment control, spill response, reclamation, and a safety plan, will also be required.

If the work is in a riparian area, permits may be required from the state and the federal government. For lateral levees, the work may actually impact a water body and may be restricted to the in-water work window as designated by the state for protection of aquatic species. In-water work requires a US Army Corps of Engineers Section 10 or 404 permit with a Section 401 certification for water quality usually obtained from the Department of Ecology.

The applicant should contact the U.S. Fish and Wildlife Service and NOAA Fisheries to determine if there are threatened/endangered species on the property or in the area. Incidental take permits may be required.

7 CONSTRUCTION CONSIDERATIONS

Consider the following elements when constructing new setback levees or removing existing levees:

- Requires large equipment in potentially sensitive habitats. Clearly designate entry and exit points and access roads. Minimize the number of roads and the number of trips by large equipment.
- Minimize clearing and grubbing. Instead trim vegetation to the ground level and cover with a geotextile during construction.
- Removal of mature riparian vegetation may be necessary to open up the floodplain. Consider saving islands of vegetation to serve as a natural seed bank and to provide at least remnant habitat while the system recovers from construction disturbance.
- Trees that are removed during construction can be used as floodplain roughness elements and as habitat features.
- Floodplain wetlands may be impacted by construction activities. Try to route construction equipment through less sensitive areas.
- Stockpile fertile topsoil for later use. Be cautious to keep soil piles small to minimize composting which will reduce the available seed bank.
- The footprint of an old levee will need to be ripped (decompacted) prior to vegetative establishment.
- To reduce soil compaction, special equipment for operating on soft ground may be required. If this equipment is not appropriate or available, ripping of the construction access areas following construction to decrease soil compaction is recommended.
- Refueling should occur outside of the active floodplain area.
- If invasive species are of concern, steam clean the equipment before it is brought on-site.
- A spill response plan should be developed and available for the construction crew.
- Construction timing should be related to soil moisture conditions, hydrological trends of the contributing water body, and to sensitive plant and animal species.

8 COST ESTIMATION

Actual unit cost estimation for Levee Modification and Removal includes but is not limited to the following items:

- Feasibility studies including hydrologic, hydraulic, geomorphic, biologic, and specific habitat studies. Costs will vary depending upon the size and scope of the project.
- Conceptual or preliminary designs.
- Contract plans and specifications.
- Permits including NEPA, ESA, Corps, state, and county permits.
- Land acquisition. Costs vary widely depending upon current land use and local land prices. The proponent should investigate within the area to determine appropriate land values. Inquiries should be made to the county auditor about changes in tax rates if the area is being converted to a different land use.
- Levee removal, augmentation, breaching, and/or construction. Levee construction/deconstruction and bank stabilization generally require mobilization and demobilization of equipment, pollution control, clearing, recontouring, and excavation, hauling, and disposal of material. Additional material for levee construction and bank protection may be necessary, which will add to overall project cost. For levee setbacks, a temporary storage area is required for the spoil material. Mobilization and demobilization costs will typically be a percentage of the total contract cost (generally 12 to 18%).
- Bank stabilization and other structures.
- Vegetative plantings. The cost for reestablishment of vegetation will vary depending upon availability of material and the labor involved in the actual planting. Advanced planning can significantly reduce costs by insuring that specific species are available in the quantities required. Native plant nurseries are becoming more common, and they will often propagate site-specific plants for future revegetation efforts if notified well in advance.
- Construction management. A critical component for project success, construction management generally costs between five and ten percent of the total project cost. This insures that someone is onsite during the entire construction period and that the project is built as designed.
- Pollution control. A relatively set cost based on the type of equipment on-site and site conditions (up to 20% of excavation cost can be used as an estimate).
- Excavation, hauling and disposal. Cost is based on the volume of material to be moved. Excavation and handling costs will range from one to three dollars per cubic yard ($1 – $3/cy). Hauling cost depends on haul distance, but general estimates can be made based on rental rates for dump trucks. A 10 to 12 cubic yard dump truck rents for approximately $30 – $50/hour. The cost for material disposal will vary greatly depending upon the condition of the material. For clean, uncontaminated material, disposal costs may be very low, or free. Contaminated soil will significantly increase cost.
- Operations and maintenance. Costs vary greatly and are project specific. Once a project design is developed, these items can more effectively be estimated.

- Monitoring and tracking. Costs vary greatly and are project specific. Once a project design is developed, these items can more effectively be estimated.

9 MONITORING

The purpose of monitoring is to determine if the goals and objectives of the project have been met, suggest changes if needed, as well as to learn more about habitat restoration projects in general. Monitoring of floodplains after the modification or removal of levees is commonly accomplished with the aid of aerial photography, digital terrain models (DTM's), satellite imagery, LIDAR, etc. Since the reconnection of streams to their floodplains can be extensive, aerial photos allow for evaluation of the entire project area. Flow paths, deposition and erosion areas, and changes in vegetation can easily be identified on appropriately scaled aerial photos. Aerial photos can be taken during various seasons to allow for evaluation of flood extent, ephemeral habitat, and plant communities. For smaller projects, photo points may be sufficient to evaluate general trends.

Specific monitoring items may include:

- Installing a simple water level recorder to determine when a floodplain becomes activated. This gage can be calibrated to other gages within the basin.
- Supplemental information may include sediment and debris lines on vegetation.
- Piezometers can be installed in the floodplain to monitor shallow groundwater levels and hydraulic gradients.
- Vegetation type and abundance can be monitored with vegetation transects. Special attention should be given to shifts in vegetative communities and the introduction or eradication of invasive species.
- Topographic surveys can be used to determine if natural topography is developing on the floodplain (if previously leveled), and the extent of side channel development. For smaller projects (e.g., 10 acres or less), total stations are appropriate for developing detailed topographic maps. LIDAR should be considered for larger projects.
- Structural components, such as bank protection or levee integrity, should be evaluated using standard engineering protocols. Specifically, an "as-built" survey should be completed after construction.

10 MAINTENANCE

Operations and maintenance applies primarily to levee setback or breaching. Full levee removal, accompanied with appropriate restoration of the floodplain, should require very little or no maintenance beyond the establishment of native vegetation.

An operations and maintenance plan should include specific instructions to insure that the levee or breach area is properly functioning. Requirements to consider include:

- Prompt repair or replacement of damaged components.
- Removal of obstructions from inlet and outlet facilities.
- Periodic check of earth fill elevations.
- Evaluation of the levee surface for cracks in the soil.

- Evaluation of eroding areas, including main channel, side channels, floodplain surface, levee surfaces, and breach areas.
- Evaluation of vegetation condition, distribution, composition, and abundance.

11 EXAMPLES

Although removing, breaching or setting back levees has substantial potential for restoration, these projects appear to be relatively uncommon and not well monitored. Simenstad and Thom[8] describe two examples located on the Salmon River estuary along the coast of Oregon, and the Elk River estuary located in Grays Harbor County on the Washington Coast.

11.1 Salmon River Estuary

The Salmon River estuary is a small (<2 km^2), drowned river valley estuary located on the Oregon coast immediately south of Cascade Head, and is considered one of Oregon's most pristine estuaries[9]. Watershed and estuarine land use moderately affect the Salmon River estuary by increasing turbidity and surface water temperatures as well as reducing freshwater flows[10]. Diked in 1961 for pastureland, a 21 ha segment of brackish marsh was reconnected to tidal inundation in September 1978. Frenkel and Morlan[11] assessed vegetation and soil characteristics at the restored estuarine marsh 11 years after the breaching of the dike. Frenkel and Morlan used two 15-ha marsh habitats occurring on either side of the dike-breach marsh as reference sites for interpreting the vegetative recolonization of the restoration site.

The sequence of vegetative recolonization did not mirror the vegetative communities present at the reference sites. Instead, the restored marsh developed into a low marsh dominated by *Carex lyngbyei* due to 35-40 cm of subsidence over the 17 years of use as pastureland. According to Frenkel and Morlan, sedimentation of the restoration marsh averages between 5 and 6 cm y^{-1} (range, 3-9 cm y^{-1}), compared to an average of 4 cm y^{-1} (range 2-9 cm y^{-1}) in the control marsh. Frenkel and Morlan also found that sediment accretion in the restored marsh was measurably higher at lower tidal elevations than at higher elevations. Frenkel and Morlan used net primary production (NPP) as the principle index of wetland function; however, other functions (e.g., fish and wildlife utilization, benthic infauna or epibenthos, nutrient cycling, etc.) were not assessed and monitored.

11.2 Elk River Estuary

The Elk River estuary drains the southwest corner of Grays Harbor. The enhancement site is a 16 ha salt marsh that was leveed and used as pastureland for over 50 years; over the period it was leveed, the site was colonized extensively by facultative freshwater wetland plants, including the exotic species *Phalaris arundinacae* (reed canary grass). In June 1987, a 10 meter gap was excavated in the levee for tidal inundation as part of wetland mitigation plan. Like the Salmon River site, the diked habitat in the Elk River estuary subsided considerably, although the precise extent of subsidence has not been measured.

Local estuarine processes adjusted to the presence of the levee by accreting on the Grays Harbor side of the levee, while subsiding on the landward side of the levee; consequently, an unusual gradient in tidal elevation developed from low marsh to high marsh (on the Grays Harbor side of the levee) to low marsh (on the landward side of the levee). The narrow dike breach combined with the elevation change between the higher, former "foreshore marsh" and the lower, new "back marsh" appears to be responsible for rapid erosion of a tidal channel at the point of the levee breach. Limited channel capacity also creates a backwater effect during an ebb tide, thus inhibiting the drainage of the tidal waters from the restored marsh area.

Monitoring habitat changes following the levee breach is limited to annual surveys of percent coverage of primary emergent wetland plants at five established points across the leveed site. Observations indicate a rapid decline in dominance of the predominantly freshwater plant assemblages to recruitment and increased dominance of facultative and obligate estuarine species of wetland plants such as *Salicornia virginica* (pickelweed), *Atriplex patula* (saltweed), and *Carex lyngbyei* (Lyngby's sedge). The restoration strategy for this site could be modified to promote more favorable results by restoring historical topography (via supplementing sediment to the landward side of the levee), removing the entire levee, and transplanting high marsh vegetation.

11.3 Other Projects

Lockwood Creek (tributary to the EF Lewis River) in Clark County, WA. Levee removal with some floodplain excavation to improve fish habitat. Project sponsor is the Clark Conservation District. Implemented in 2000.

Spencer Island Wetland Restoration in Snohomish County. Built a cross levee and breached an existing levee to recreate a tidally-influenced, freshwater wetland on 400 acres in the Snohomish River Estuary. Sponsored by Snohomish County Parks. Designed by Entranco.

Deepwater Slough Section 1135 Restoration Project near Conway, Washington[12]. Levee breach, levee removal, new dike construction and dike augmentation by the U.S. Army Corps of Engineers. Constructed in 1999.

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