6

Formulating a Levee Project

Key Messages

This chapter will enable the reader to:

- **Consider levees in the context of flood risk.** A levee is one of many measures that may be employed as a flood risk reduction strategy. Levee formulation should ensure levees do not contribute significantly to flood risk.

- **Be ecologically and socially aware.** Consider ecological and social risks and opportunities while holding life safety paramount. Pursue solutions that incorporate the natural environment and support the everyday functioning of the local community.

- **Follow and iterate the planning process.** The well-established six-step process should guide formulation. As alternatives are developed, evaluated, and compared, the understanding of risks may change, resulting in the return to a previous step or re-formulation.

- **Evaluate multiple alternatives.** Use a transparent process to compare potential benefits and adverse impacts of multiple project alternatives. Consider life safety, economic and environmental benefits or impacts, and social equity in the evaluation.


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Other chapters within the National Levee Safety Guidelines contain more detailed information on certain topics that have an impact on formulating a levee project, as shown in Figure 6-1. Elements of those chapters were considered and referenced in the development of this chapter and should be referred to for additional content.

Figure 6-1: Related Chapter Content

CH 1	CH 2	CH 3	CH 4
Flood risk management strategies	Types of levee projects	Engaging about levee projects	Identifying flood risk Vulnerability
CH 5	**CH 6**	**CH 7**	**CH 8**
Risk-informed decision making Levee risk management	**Formulating a Levee Project**	Levee design considerations	Construction considerations Construction documentation
CH 9	**CH 10**	**CH 11**	**CH 12**
Operating and maintaining a levee		Reconnecting the floodplain	Incorporating community resilience

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1 Introduction

This chapter is focused on how to formulate a levee project. The guidance in this chapter applies when a community has gone through a process to understand their flood risk and has decided to pursue a flood risk management strategy that includes a levee. A generic planning process—as well as the unique consideration associated with formulating a levee project—are covered in this chapter.

Principles of levee formulation described in section 2 should be carried throughout the levee formulation process and into final design and construction. In addition to principles, several best practices and considerations are described for the reader to keep in mind as decisions are being made. Best practices are ways in which to achieve the overarching principles.

The goal of planning is to identify a cost-effective, technically feasible, and socially and environmentally responsible solution that meets project objectives. A step-by-step planning process is presented to provide a structured, scalable approach to develop alternatives and select the most appropriate levee project that aligns with a community's values. Throughout the planning process, analyses and evaluations are required to advance to next steps in the process. Descriptions of these analyses and the results used to establish levee characteristics are provided.

Typical readers of this chapter are those that are involved in the planning and design of a levee project including planners, engineers, levee owners/operators, decision makers, and other stakeholders affected by the project.

2 Levees as a Flood Risk Reduction Strategy

As discussed in **Chapter 1**, a comprehensive flood risk management strategy should reduce the risk of human and socio-economic losses caused by flooding and improve the resilience of communities against flood impacts. Some communities have already specified flood risk reduction strategies in their state or local hazard mitigation plans (**Chapter 11**). **Chapter 12** describes a communities' need to understand its exposure to flood risk, its greatest vulnerabilities, and carries forth the principle of achieving community resilience. Best practices for achieving community resilience may be categorized under four groups of actions:

- **Prepare**: Community education and awareness, individual actions, and community emergency planning.
- **Absorb and resist**: Structural (e.g., levee) and nonstructural measures, stormwater drainage systems, land use planning, property acquisition, and building codes.
- **Restore and recover**: Flood insurance, recovery plans, grants, and emergency funding.
- **Strengthen and adapt**: Continual assessment of resilience and identification of new or improved ways to achieve resilience goals.

To sustain resilience, communities should consider various combinations of structural, nonstructural, and nature-based measures to achieve flood risk reduction goals; levees are just one measure.

The selection of a flood risk reduction measure depends on many factors, including, but not limited to flood risk drivers and the effectiveness of a given measure in addressing risks, achieving environmental goals, understanding physical project constraints, availability of funding, and existing regulations, policies, and practices. A wide array of measures and actions have potential to reduce flood risk to life, health, and property while also restoring natural floodplain resources. Whatever measures are selected, it is essential that the flood risk management strategy—including land use decisions—supports community values and aligns with the long-term vision and goals for community development and priorities regarding what to protect and to what level. The likelihood of successful implementation—from taking a conceptual idea through the formulation, design, permitting, construction, and long-term O&M—should be addressed at the onset of a project.

It is also good practice to use redundant and complementary risk reduction measures. This redundancy increases the likelihood of successful reduction of flood impacts, even if one measure fails or does not perform as expected. An example of a redundant flood risk reduction measure might be a backup power supply for automated closure gates in case the primary power source is lost during a flood event. Communities should seek solutions to reduce flood risk that promote community values and align with its long-term vision related to residential and commercial development and the protection of assets. Examples of actions that communities can take to better understand and/or reduce the consequences of flooding are provided in **Chapter 1**.

The practices presented in this chapter are intended for new levees, if selected as a viable part of the risk reduction strategy, or for existing levees that require rehabilitation or modification to continue to be viable for a community's unique situation. These practices also apply to planning for a levee removal for situations where the levee is no longer a viable flood risk reduction strategy for a community. The overarching principles that should be central throughout levee formulation are:

- Hold life safety paramount
- Do no harm
- Enhance natural resources
- Make risk-informed decisions
- Reflect community values, goals, priorities, and risk tolerance
- Align with management of the floodplain

The goal of levee formulation is to select a preferred levee alternative that provides acceptable solutions to identified flood risk problems while considering the environmental setting. Levee project formulation includes establishing:

- **Top of levee profile**, including the level of flood risk to be provided, required levee height, and design of controlled overtopping section(s), if practical.

- **Levee alignment**, including setting back the levee to promote floodplain function and tie-ins to the natural ground or human-made structures whenever possible.
- **Levee footprint**, including crown width, levee slopes, and required right of way for the maintenance corridors.
- **Levee features** and other project elements to achieve the project objectives, such as designed environmental features that will work in concert with the levee.
- **Nonstructural actions**, including flood warning systems, evacuation planning, and community engagement to manage flood risk and levee risk once the levee is in place.

The levee configuration may be composed of multiple features that together comprise a whole systems approach that acts as a barrier to help prevent floodwater from entering the leveed area. The levee formulation process should demonstrate that the selected project is cost-effective and justified to achieve the desired objectives. The formulation process is successful when the proposed levee project is implementable, supported by the affected communities and is aligned with broader floodplain management goals for the community, county, state, and larger region. Most importantly, the decision to construct or modify a levee should be made with the understanding that levees do not eliminate the flood risk, but if implemented as part of a comprehensive flood risk management strategy, they can reduce risks to desired levels.

3 Planning Process

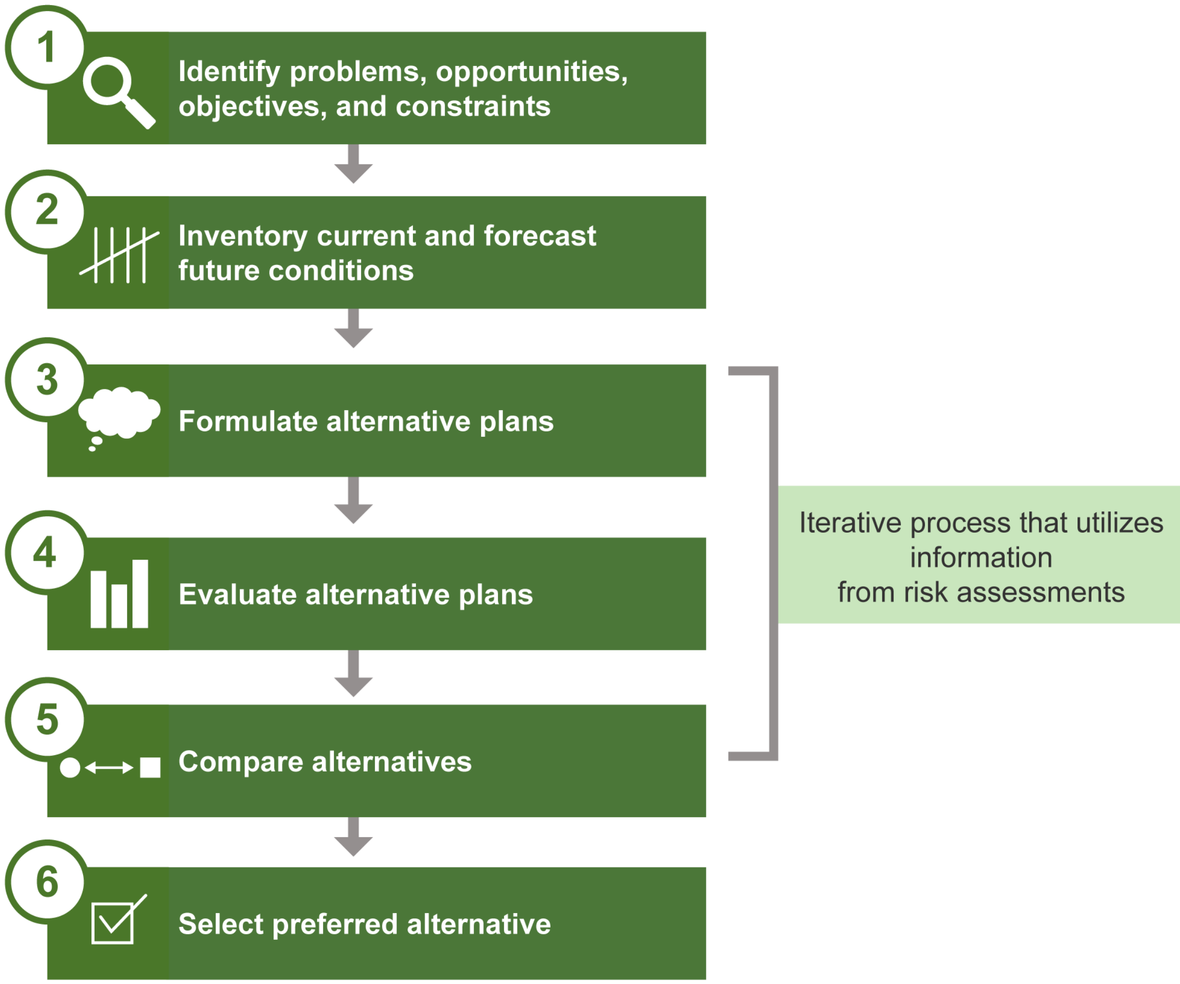
The generalized planning process defined herein and shown in Figure 6-2 is a structured, scalable approach with a framework that can be applied to any levee project.

This planning process is iterative and adaptive. As more information becomes available, it may be necessary to circle back to some of the previous steps. The steps may be done sequentially or concurrently—and could also be combined or abbreviated as appropriate—depending on the complexity of decisions. Regardless of the level of detail selected, risk assessment is an integral part of the planning process and should be performed throughout the six steps identified in Figure 6-2. As the formulation process moves through Steps 3 through 5, alternative plans may be adjusted to consider various constraints and opportunities, which could result in a change to one or more aspects of flood risk (i.e., levee risk, non-breach risk, or flood risk from other sources). As these risks are estimated, it may be necessary to return to an earlier step in order to make adjustments based on the assessment of risk.

The planning process should begin with scoping, which is initiated to lay the ground rules for levee planning. It includes defining the required level of detail of analyses, identifying areas of uncertainty, and engaging with parties involved in the planning process, as well as those affected by implementation of the project.

The purpose of scoping is to obtain the perspectives of others and build consensus on goals and objectives so that the desired outcome is clearly understood and broadly supported.

Figure 6-2: The Formulation Process



Recall the different types of levee projects described in **Chapter 2** and shown in Figure 6-3. Formulation for a levee project is needed for all levee project types except repair. Issues leading to a repair project, such as undesired vegetation or encroachments, likely have an obvious cause and the solution is straightforward, not lending itself to the need for evaluation of multiple alternatives.

Figure 6-3: Types of Levee Projects

Depending on the type of levee project, the plan formulation steps may vary.

3.1 Planning Team

The plan formulation process should be performed by a multidisciplinary team, including:

- Planners/project managers
- Engineers
- Risk assessment experts
- Environmental and cultural resources experts
- Community representatives

Depending on the objectives of the study, there may be experts with specialized expertise who need to be added to the team. Scientific professionals well versed in sediment transport, fluvial geomorphology, fish biology, botany, forestry, ecology, and soil science can assist in planning and design processes for levees.

It is recommended to involve experts to assist with choosing plants that are native and have the most desirable qualities. Specifically, a botanist or forester could have significant expertise in how trees will respond to their environments—including how roots can be expected to grow based on species characteristics and local hydrology. A soil scientist could provide valuable information about how water will move through the soil profile and how to optimize or discourage plant growth using compaction and texture selection. A botanist, biologist, or ecologist can provide information of what types of plants—herbaceous and woody—to plant based on the goals of the project and the expected conditions.

Other disciplines to consider include real estate professionals, economists, archeologists, and tribal liaisons.

3.2 Step 1: Identify Problems, Opportunities, Objectives, and Constraints

The first step of the planning process is identifying the area-specific problems and opportunities for study (Figure 6-4). Problems and opportunities should be framed in terms of the specific planning objective. Project constraints are also identified in this step. The following general definitions are specific to the planning process:

- **Problems:** The issues that the project is intended to address (e.g., flood risk reduction). Once defined, they guide efforts to develop solutions.
- **Opportunities:** Issues other than the problem that could be addressed with the project and/or benefits that could be realized as part of the project.
- **Objectives:** Statements of the desired results of the project to address the problem and realize opportunities. Objectives should describe measurable outcomes of the project.
- **Constraints:** Restrictions on the project from outside sources such as legal, policy, environmental, or other resource considerations.

Figure 6-4: Plan Formulation—Step 1

1

Identify problems, opportunities, objectives, and constraints

What problems are we solving?

What criteria contribute to acceptable solutions?

What peripheral opportunities may be incorporated into the solution?

Examples of potential problems, opportunities, objectives, and constraints by levee type are shown in Table 6-1. The problems and opportunities should be specific to the planning area. When considering construction of a levee, the problem might be a specific flood hazard to be addressed. Refer to **Chapter 1** for a discussion on understanding flood risk. Information in this chapter will inform identification of the problem for new levees. Refer to **Chapter 5** for methods to identify problems for levee rehabilitation and modification projects.

Examples of opportunities include increasing climate change resilience, incorporating nature-based solutions to benefit the environment, considerations for adaptive management measures (section 4.3) to iteratively address changing circumstances or new information received about the project, recreational features, and public spaces. All potential opportunities should be documented and considered in early stages of plan formulation. Priorities and preferences of those impacted should be understood and incorporated, thus community engagement at this early stage is strongly encouraged.

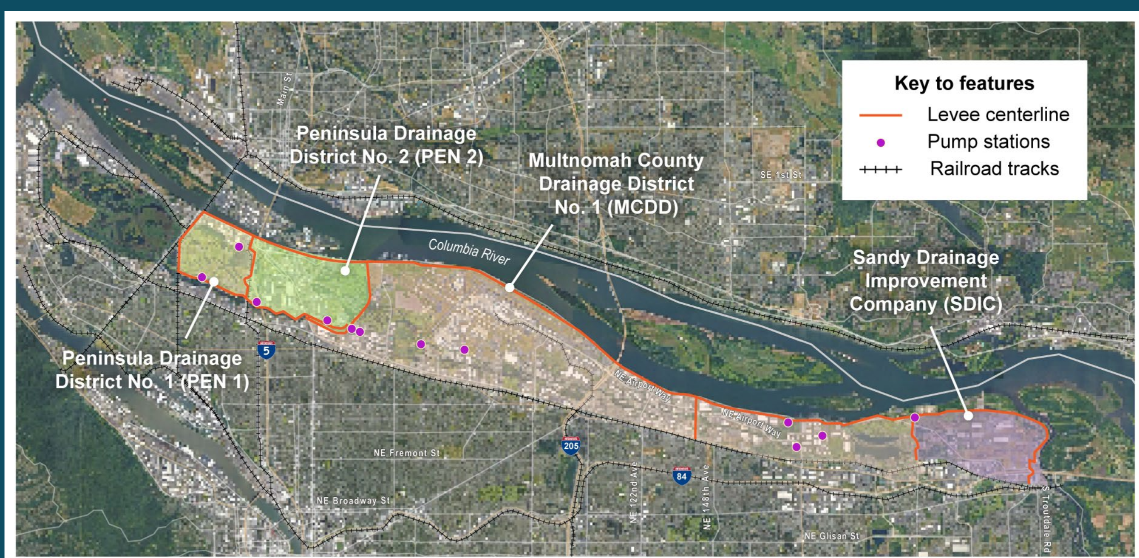
Once problems and opportunities are identified, objectives and constraints should be defined to guide planning efforts. Objectives are clear and concise statements aimed to solve problems and realize opportunities. They should include information about the desired outcome, location of where results will occur, and timing and duration of the effect. The objectives should consider current and future conditions. Constraints are restrictions, obstacles, or limitations on solving identified problems and realizing opportunities. Typical constraints are often related to limited resources, including expertise, data, funding, or time. Legal and policy constraints may also limit the ability to meet project objectives.

Project-specific constraints might include areas where land acquisition will be difficult, avoiding protected environmental habitat or species and sensitive cultural resource areas, laws or regulations, risk transfer and risk transformation considerations, or inadequate resources. Constraints should be identified early on, but may change between planning, design, and construction. Often, funding sources will be dictated by state and/or federal programs, with specific qualifying metrics to obtain that funding. While setting project objectives, it is important to keep potential funding opportunities in mind as the life of the project can be limited by a lack of appropriate funding. Identifying constraints early helps illustrate options that simply are not possible.

STEP 1 EXAMPLE: PORTLAND METRO LEVEE

The project study area lies along the Columbia River in Oregon and includes 27 miles of levees with several cross levees that reduce the risk of flooding for the cities of Portland, Gresham, Fairview, and Troutdale. Built in 1917, this system of levees and pump stations was intended to provide critical flood risk reduction and stormwater management.

- Problems: Flood risk varies along the levee reach and a railroad at the downstream end of the study area was not designed as a levee, but is integral to excluding flood waters from the leveed area. Operation and maintenance (O&M), as well as access for inspection on this portion of the embankment, are prohibited by the railroad. In addition, there are multiple low spots and missing or incomplete sections of floodwall, lack of redundancy for pump stations, and portions of the levee that do not meet current standards.
- Opportunities: Reduce the likelihood of life and economic loss due to flooding, increase the ability to floodfight, increase recreational opportunities, maintain the existing natural and cultural resources, and increase public awareness of flood risk.
- Objectives: Reduce flood risk in a manner that minimizes impacts on resources and is acceptable to the community.
- Constraints: Cross levees will stay in place, the railroad embankment will not be considered part of the levee system, and existing road infrastructure such as bridges will not be modified.



(USACE Portland District and Columbia Corridor Drainage Districts, 2021)

While states and communities regulate and manage floodplains ultimately to reduce flood damages, it is important to also emphasize that flood risk management activities can provide opportunities to align with other community goals and achieve multiple benefits, such as recreational, environmental, social, or cultural benefits. Representatives from state regulatory bodies, scientific professionals, and tribal experts well versed in the local aspects of sediment transport, fish biology, botany, and archaeology are important to include in the planning process. Identifying opportunities that promote multiple benefits across a community can help to obtain additional funding sources and staffing by both municipal and non-governmental organizations. Perhaps more importantly, a solution that embraces a variety of techniques to reduce flood risk and promotes other community goals is more likely to retain long-term community-wide support.

Table 6-1: Step 1: Typical Problems, Opportunities, Objectives, and Constraints by Project Type

Levee Project Type	Problems	Opportunities	Objectives	Constraints
New	• Flood risk hazard has been identified	• Incorporation of nature-based features • Co-benefit opportunities • Adaptive management • Enable other land uses • Recognize environmental justice • Recreational development • Alignment with public values	• Reduce flood risk	• Difficult land acquisition • Disturbance of environmental habitat or species • Disturbance of sensitive cultural resource areas • Laws or regulations • Risk transfer • Funding for planning, design, construction, long-term O&M • Natural environment: topography, soils, population, existing structures or utilities, water surface level • Staffing/expertise for long-term O&M • Governance to manage O&M • Climate change • Inadequate resources • Presence of hazardous, toxic, or radioactive waste
Rehabilitate	• Existing levee no longer provides flood risk reduction as design intended	• Incorporation of nature-based features • Co-benefit opportunities • Alignment with public values	• Provide/restore level of risk reduction as designed • Reduce levee risk	
Modify	• Need for increased level of risk reduction • Identify how levee modification might change level of risk reduction	• Incorporation of nature-based features • Co-benefit opportunities • Adaptive management • Enable other land uses • Recreational development • Alignment with public values	• Reduce flood risk, including levee risk	
Remove	• Existing levee is in a state of failure • Need for ecological restoration • Need for floodplain storage during a flood • Need for groundwater recharge • Existing levee is being rerouted or replaced (e.g., setback levee) • Other flood risk mitigation features have made the levee functionality obsolete • Change in potential consequences (lives and property)	• Create or enhance native habitats within previously leveed area • Groundwater recharge and/or flood-managed aquifer recharge • Co-benefit opportunities • Floodplain storage during a flood • Managed community retreat • Recreational development • Enable other land uses • Alignment with public values	• Maintain or reduce the risk to human life • Maintain or reduce the risk of economic damage to businesses, residences, manufacturing facilities, and critical infrastructure (e.g., agriculture, medical centers, schools, roads, bridges, fuel, and energy production and distribution facilities) • Maximizing ecological benefit • Maximizing multiple opportunities/benefits such as recreation, aquifer recharge, geomorphic processes, agricultural, etc. • Minimizing the need for long-term maintenance • Incorporating climate change and sea-level rise considerations	• Difficult land acquisition • Disturbance of environmental habitat or species • Disturbance of sensitive cultural resource areas • Laws or regulations • Risk transfer • Funding • Topography • Soils • Exposure (who and what are in harm's way) • Climate change • Inadequate resources • Public acceptance • Presence of hazardous, toxic, or radioactive waste

3.3 Step 2: Inventory Current and Forecast Future Conditions

This step includes inventorying current conditions and forecasting future conditions relevant to the problems and opportunities identified in Step 1. Information gathered in this step further refines the problems and opportunities by providing quantitative or qualitative descriptions of the current and future with or without-project conditions (Figure 6-5). Conditions to consider that may change over time include:

- **Topography of the project site**: This should include existing and any future anticipated changes to topography of the project area that would impact flood flow through the watershed or channel.
- **Geotechnical and geological characterization:** Investigation of subsurface conditions that could impact the selection and scale of various project features is required. Soil type and hydraulic properties of subsurface materials will impact construction considerations and longer-term levee sustainability.
- **Existing or planned infrastructure and land use:** The types of infrastructure and other aspects of the current and future areas that may or may not be protected by the flood risk reduction strategy. Conversion from open space or rural areas to more developed urban areas should be investigated and included in the future condition.
- **Ecological, cultural, and tribal resources:** Factors that could potentially impact the selection of the type and location of flood risk reduction measures should be considered.
- **Exposure (property, people, environment, cultural)**: Exposure incorporates a description of where the flooding occurs at a given frequency and what exists within that floodplain (**Chapter 4**). Tools such as flood inundation maps showing extent and depth of flooding, structure inventories, population data, crop data, and habitat acreage illustrate exposure. Consideration should be given to areas of planned or anticipated development, areas of natural ecosystems, and locations of cultural resources. Additionally, consideration should be given to the diversity of the community including but not limited to those who are unhoused, have lack of access to resources, are disabled, or have limited English proficiency. Consideration should also be given to areas that include structures with large populations that include schools, hospitals, nursing homes, or correctional facilities.
- **Flood conditions at levee**: Hydrologic and hydraulic analyses of river and coastal wave and water level conditions are required to estimate flood water surface levels and potential floodplains for various conditions (i.e., without project, with project, and considering levee failure or misoperation). Flood levels and frequency of flooding may change over time.
- **Climate change**: With anticipated increases in temperature and precipitation frequency and intensity, potential for increased runoff and resulting water surface elevation and sea level rise should be included in future forecasts. Future forecasts should include more climate change impacts to levees than have occurred historically, and in many cases, plan for new impacts from weather that previously may not have posed significant threats.

- **Hazardous waste**: An early assessment of potentially hazardous waste contamination should be conducted as early as practical. The assessment should include the existence of, or potential for, contamination on lands—including structures and submerged lands—in the study area. Investigations should also address lands external to the study area that could contribute hazardous waste to the study area that could impact or be impacted by the project.

Figure 6-5: Plan Formulation—Step 2

2

Inventory current and forecast future conditions

What is the environment in which the proposed solution must exist?

Do projections exist for future climate conditions?

How certain are we about future projections?

How might changes in land use affect the proposed project?

How might the project change existing land use?

Forecasting future conditions requires research and technical analyses. Research might include investigating a community's development plans, construction of transportation facilities such as roads, highways, or rail systems, or estimating population growth. Technical analyses may be required to forecast future climate conditions using the latest climate science and models. Since future conditions are unknown, uncertainty should be included with forecasted future conditions.

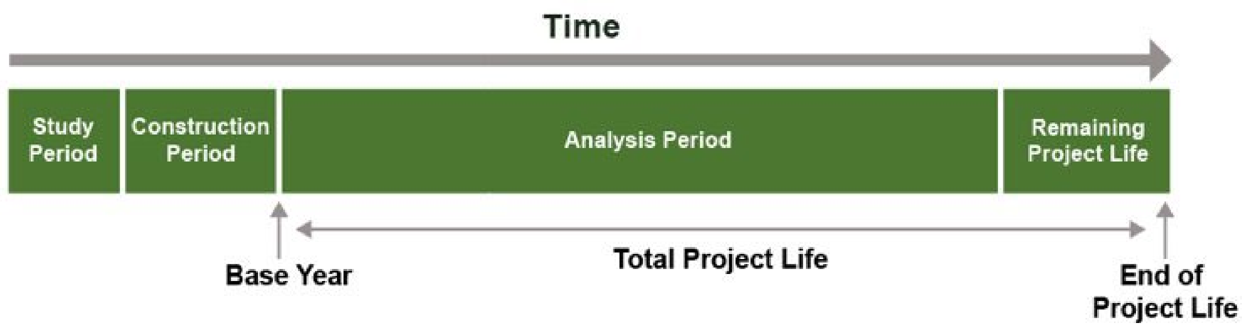
Uncertainty should be characterized—quantitatively and/or qualitatively at the commensurate level of detail—for all levee projects. Assumptions used in forecasting/projecting future conditions should be clearly and explicitly documented. Where uncertainty may meaningfully impact the investment decision, multiple baselines can be used, with a clear explanation of the basis and assumptions underlying each. Climate change (i.e., how the climate changes over time) and climate variability (i.e., swings in climate conditions exacerbated by climate change) are highly uncertain and should therefore be captured in the definition of future conditions.

Analyses and investigations required to inventory and define existing and future conditions can be costly and time intensive. The effort of the analysis should be scaled to fit the study area and align with the resources and data available. For example, staffing resources to investigate current and future conditions might not be readily available and flood risk and/or potential consequences may be few. In this case, the level of effort spent in investigating current and future conditions might be scaled back. However, where potential consequences from flooding are likely high, a larger effort should be expended on establishing current and estimating future conditions.

Forecasting future conditions requires developing and understanding the project life and key milestones for the project. The National Economic Development Procedures Manual (Scodari, 2009) defines the planning horizon for the economic analysis of a project as including the study period, construction period, base year, period of analysis, and project life, as shown in Figure 6-6.

- **Study period:** Initiation of the study to the initiation of project construction.
- **Construction period:** Project installation.
- **Base year:** The point in time when the project is functionally operational. Usually, the base year coincides with the end of the construction period.
- **Analysis period**: Base year to some number of years (generally 50 for levee projects) into the future.
- **Project life:** Period that a normally operated and maintained project will function as it was designed. For most water resources projects, the project life exceeds the analysis period. For example, if a levee is properly designed, constructed, operated, and maintained, the life expectancy of that levee often exceeds the planned 50 years.

Figure 6-6: Project Timeline



To compare a project's benefits and costs that may accrue unevenly over the planning horizon, two points in time must be selected where these values will be compared. Typically, this is the base year, which can be considered as the current condition. The future condition is typically the end of the analysis period, which for a levee project is typically 50 years or more. However, for large scale multi-purpose projects with additional infrastructure, a longer project life may be more appropriate and used. The same project timeline should be used for each alternative evaluated. Other items to allow time for in the overall schedule of a levee project might include:

- Environmental constraints or permitting requirements that could cause delays in site work for certain times of the year.
- Engagement with the public.
- Consultation with tribal nations if tribal lands or cultural resources are expected to be impacted.
- Land acquisition.
- Legal requirements.

Through the process of forecasting future conditions, additional opportunities and constraints may be identified that require revisiting Step 1. For example, if new development within the planning area is anticipated, the opportunity to include recreational trails or ecosystem educational stations along the project alignment may be considered. Conversely, new development may pose problems not present before, such as increased interior drainage or the new community may not support the project if their concerns were not considered as part of the formulation and design of the project.

3.4 Step 3: Formulate Alternative Plans

Alternatives are formulated to achieve the planning objectives by solving the identified problems and realizing opportunities, while taking into account known constraints (Figure 6-7). Alternatives might include structural or nonstructural measures, strategies, or programs (Table 6-2). When formulating alternatives, it is important to understand levee risk and incorporate the management of those risks into the potential solutions. More information can be found in **Chapter 5**.

Figure 6-7: Plan Formulation—Step 3

3

Formulate alternative plans

What are specific ways to achieve project objectives while avoiding constraints and maximizing opportunities?

How can structural, nonstructural, and nature-based solutions be included in alternative plans?

Life safety is the primary consideration in alternative formulation, but are there other measures to include that provide a co-benefit?

Individual measures that address specific project objectives are identified first. These measures will become the building blocks for plan formulation and may include structural, nonstructural, or nature-based solutions. Individual measures may be combined to form a broad spectrum of alternatives, ranging from no action to robust activities. Screening out options from consideration is not part of this step since eliminating measures too early may bias the selection of those measures that remain under consideration. It is an iterative process where all feasible combinations of measures are considered.

Some alternatives might be better at addressing one objective over another. Alternatives should be developed with life safety at the forefront, while also considering economic and environmental benefits or impacts and promoting social equity. For example, enhancements that advance environmental goals might include infrastructure that reduces greenhouse gases, limits sediment deposition, or enhances habitat. This is the first step of the plan formulation process that could be iterative based on new information developed during the planning process. Refer to **Chapter 12** for ideas on incorporating community resilience into alternatives.

Future conditions forecasted in Step 2 of the planning process are uncertain, which may lead to formulating alternatives that either do not meet or possibly exceed the objectives. Adaptive management strategies should be considered at this point in the planning process to adjust to future needs (see section 4.3). For projects where the level of uncertainty of future conditions is high, alternatives that include adaptive management strategies will enable flexibility in investments over the life of the project and provide the appropriate level of benefits for each adaptive change made.

Typically, a 'no action' condition is included in the development of alternatives. Taking no action defines the condition of the project area if left alone (i.e., nothing is done to address the identified problems). The 'no action' alternative provides a benchmark to compare alternatives. For alternatives to be considered, they should convincingly demonstrate that they would be preferred over the 'no action' condition.

Table 6-2: Step 3: Example Considerations for Developing Alternative Plans by Levee Type

Levee Project Type	Considerations
New	• No action • Levee alignment (embankment, floodwall, tie-ins) • Levee overtopping location and elevation • Incorporation of ecosystem restoration features, including seeding, planting, and irrigation (if needed to meet project objectives) • Complementary nonstructural measures (flood warning systems, evacuation/emergency planning, land use planning, community outreach) • Incorporation of features with co-benefits, such as nature-based features • Minimize future maintenance requirements
Rehabilitate	• No action • New technologies to restore original levee functionality • Incorporation of ecosystem restoration features, including seeding, planting, and irrigation (if needed to meet project objectives) • Minimize future maintenance requirements
Modify	• No action • Options to decrease operations and maintenance burden • New levee overtopping elevation • Levee realignment • Features to achieve new elevation or alignment • Increased levee reliability • Complementary nonstructural measures (flood warning systems, evacuation and emergency planning, land use planning, community outreach) • Incorporation of ecosystem restoration features, including seeding, planting, and irrigation (if needed to meet project objectives) • Incorporation of features with co-benefits, such as nature-based features • Minimize future maintenance requirements

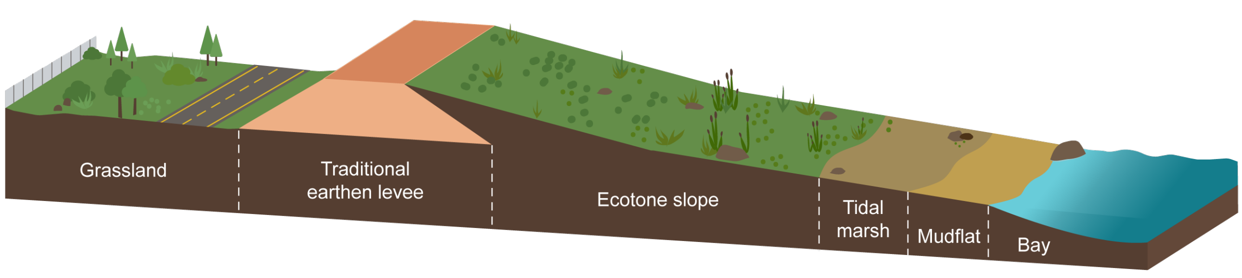
Levee Project Type	Considerations
Remove	• No action • Extent (vertical and horizontal) of levee removal required to meet project objectives • Locations to place excavated levee material • Reevaluation of what was once interior drainage, inclusion of features to safely convey drainage from adjacent areas to a waterbody • Incorporation of ecosystem restoration features, including seeding, planting, and irrigation (if needed to meet project objectives) • Incorporation of features with co-benefits, such as nature-based features • Minimize future maintenance requirements

INNOVATIVE AND EMERGING TRENDS: HORIZONTAL/ECOTONE LEVEES

Many coastal and bayside communities are installing what is known as a horizontal levee, also called an ecotone levee, seaward of a traditional earthen embankment (Figure 6-8). This consists of a vegetated berm at a much gentler slope than the main embankment, naturally vegetated with native plants that transition from upland coastal species to aquatic species. Other elements to an ecotone levee could be installation of oyster/mussel beds and sand berms. Such ecotone levees provide a number of co-benefits. The gradual slope and natural vegetation provide a significant buffer which reduces wave heights, storm surge, and coastal flooding, allowing smaller and less costly traditional levees to be built or maintained. They also provide important habitat restoration, coastal ecology, and potential recreation opportunities.

Maintenance on ecotone levees is generally less costly and intensive than that of traditional earthen embankments as vegetation is left ‘natural’ and significant management is not required. The ecotone slope reduces impacts to the traditional levee behind it, lowering maintenance and repair within the traditional earthen embankment, as well. However, the ecotone habitat must be inspected annually and maintained as necessary to keep it healthy and effective. Generally, inspection should include water quality testing and monitoring of the ecotone geomorphology. Vegetation should be inspected to meet specific design criteria. Maintenance should include debris removal, replacing or restoring vegetation or oyster beds, adding sand or sediment to assist in vegetation establishment, and adjusting any berms as needed (Figure 6-8).

Figure 6-8: Ecotone Levee Slope



3.5 Step 4: Evaluate Alternative Plans

Step 4 includes developing quantitative analyses and qualitative narratives that can be used to compare alternative plans. The evaluation should compare future conditions with and without the project and with each alternative in place (Figure 6-9).

Figure 6-9: Plan Formulation—Step 4

4

Evaluate alternative plans

- **What difference do the various alternative plans create?**
- **How will benefits be measured?**
- **What types of benefits and/or adverse effects are expected with each alternative?**
- **What is the magnitude of these effects?**
- **What is the timing and duration of effects?**

The without-project condition should reflect the most-likely conditions expected in the future in the absence of a project; the future without-project is the standard against which all plans are evaluated. Each alternative plan is evaluated by comparing the with- and without-project conditions to determine the plan's benefits and impacts. Therefore, a with-project condition must be forecasted for each alternative plan. Consistent criteria to evaluate the alternative plans is developed and might include required resources, meeting the study planning objectives, and compliance with applicable policies. Beneficial and adverse impacts should be characterized for each alternative taking into consideration magnitude, location, timing, and duration.

Multiple planning scenarios and alternatives should be evaluated to identify sustainable and resilient solutions. Analysis of project benefits and potential adverse effects should be evaluated for each alternative using the most likely future condition with project features in place. Differences between with- and without-project conditions for all selected project evaluation metrics should be quantified or described qualitatively. The future condition should include assumptions about climate conditions and potential land use changes.

Alternative evaluation also includes a preliminary screening of alternatives to identify those that will be carried forward and compared. The alternative screening is not based upon comparison with other alternatives, but solely upon the ability of each alternative to solve problems and meet objectives, while taking advantage of opportunities within the identified constraints. Care should be taken to not screen out options too early in the process.

Consistent evaluation criteria and metrics that will be used to estimate the benefits and potential adverse impacts of each alternative plan and the extent to which it meets the project objectives should be specified early in the planning process. **Life safety is paramount** and must be considered in alternative plan evaluation. Life safety benefits are difficult to relate to a dollar value, but risk assessments offer a method for quantifying the remaining life safety risk associated with various plans to allow life safety benefits to be understood and compared. **Chapter 4** provides information on how life safety risks can be evaluated and compared. **Chapter 5** discusses the use of risk information to evaluate an alternative.

A **benefit-cost analysis** is conducted to determine the benefit-cost ratio, which is often used to compare and justify alternatives. However, benefits not typically included in a traditional benefit-cost analyses should also be considered. For example, flood risk reduction alternatives for a small community may not yield economic benefits equivalent to an urban area due to fewer structures and subsequently less structural damage, but may include significant life safety, environmental and cultural benefits. These other project benefits are difficult to quantify and may need to be accounted for qualitatively. Similarly, an effort should be made to include all project costs; often the benefit-cost analysis only includes project construction costs. Other expenses such as operation, maintenance, repair, and rehabilitation costs can be significant and should be considered for inclusion in the overall evaluation of alternatives. Examples of benefits, co-benefits, and costs for a project are shown in Table 6-3.

EXAMPLES OF PLAN EVALUATION FRAMEWORKS

There are several frameworks for evaluating alternatives. Examples:

- SMART Planning (USACE, 2015).
- Broadening Benefits and Anticipating Tradeoffs with a Proposed Ecosystem Service Analysis Framework (Wainger *et al.*, 2023).
- Benefit Accounting for Nature Based Solutions (Brill *et al.*, 2021).
- California Department of Water Resources: Handbook for Assessing Value of State Flood Management Investments (California DWR, 2014).

Project specific evaluation frameworks can also be developed.

Table 6-3: Step 4: Example Benefits, Co-Benefits, and Costs

Benefits	Co-Benefits	Costs
• Life safety • Flood damage reduction • Possible reduction of flood insurance rates	• Recreational • Social • Habitat creation/ restoration • Social equity	• Construction • O&M • Emergency response • Property acquisition • Permitting • Environmental mitigation

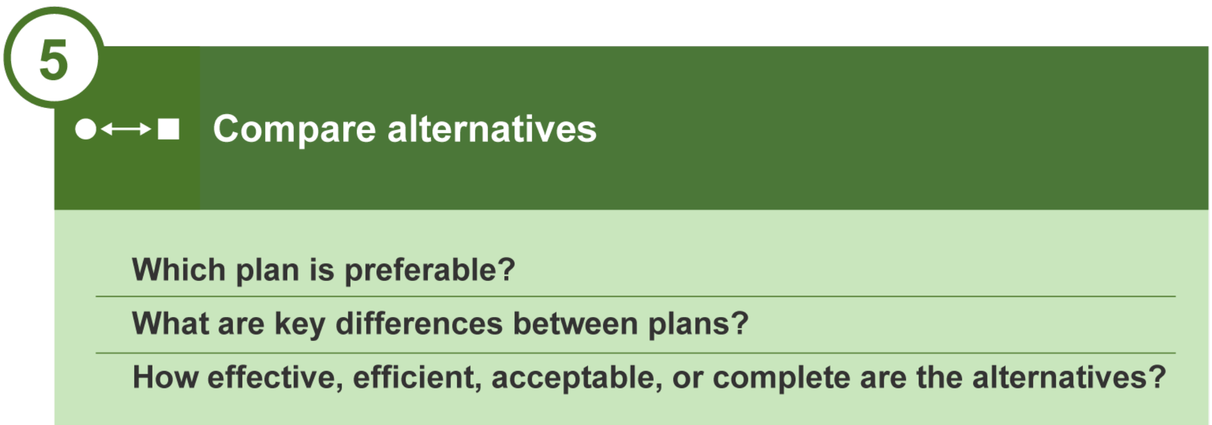
Supporting analyses should be scaled to fit the study area and align with the resources and data available. In general, analyses to be performed include those that help characterize life safety risks, social impacts such as equity, environmental impacts, flood risk reduction benefits (including cost-benefit ratio), and any other project-specific metrics.

be developed that includes project specific criteria that alternatives would be evaluated against. Project specific criteria might include weighing environmental benefits against structural damage reduction or community support. No matter what evaluation framework is selected, it should be established by the project planning team at the beginning of the planning process. How benefits are quantified or qualified, how they will be scored, weighted, or evaluated must be clear and agreed to before evaluation can begin.

3.6 Step 5: Compare Alternatives

Step 5 compares the analyses and narratives of the alternative plans against each other with a focus on their outcomes (Figure 6-10). This comparison should include consideration of a no action plan. The outcome will be a ranking of alternatives.

Figure 6-10: Plan Formulation—Step 5



Comparison of alternative plans is focused on effectiveness, efficiency, acceptability, and completeness, along with other identified project-specific criteria. At this stage of the planning process, certain criterion might be weighted more heavily than others based on the primary intended outcome. In addition to effectiveness, efficiency, acceptability, and completeness, resilience and sustainability should also be considered in plan comparison.

Both resilience and **sustainability** measure a levee's ability to meet its original objectives over time. Resilient alternatives should sustain climate-related changes and maintain its intended level of performance over the life of the levee. Sustainable alternatives need to balance environmental, economic, and social impacts of today, while having the ability to retain and maintain that balance into the future.

3.6.1 Effectiveness

Effectiveness is the extent to which a plan contributes to addressing problems and achieving objectives. An effective plan makes a significant contribution towards the solution. The most effective alternatives make significant contributions to not just a single objective, but to all the planning objectives. If the functionality or success of an alternative is uncertain, or less certain than another alternative, its effectiveness may be compromised and should be further investigated. For levee projects, the focus for effectiveness is likely in terms of the amount of risk reduction achieved with the alternative.

3.6.2 Efficiency

Efficiency is the extent of cost effectiveness of an alternative plan in alleviating problems and realizing opportunities. Some potential metrics to evaluate efficiency include dollars per unit of economic benefit, least cost of attaining a given objective, or reduced opportunity costs relative to accomplishing other alternatives.

3.6.3 Acceptability

Acceptability is the workability and viability of the alternative plan with respect to acceptance by state and local entities and the public, and compliance with existing laws, regulations, and public policies. Specific criteria for acceptability should be developed in coordination with other federal and state agencies, stakeholders and community members, tribes, and the project owner/operator. Criteria typically includes impacts to natural, cultural, and socioeconomic resources, potential to develop adequate mitigation in the vicinity, willingness of private parties to sell affected lands and facilities, and compliance with existing authority. The ability to implement the project also informs a project's acceptability. The alternative should be feasible from technical, environmental, economic, financial, political, legal, institutional, and social perspectives.

STEP 5 EXAMPLE: PORTLAND METRO LEVEE

The Portland Metro Project conducted an investigation about the future of the area without the project. The investigation included detailed engineering and economic evaluations to quantify flood risk and the population at risk (Step 1). Through several iterations of measure identification and screening, alternatives were developed (Step 3) and evaluated (Step 4) based on how well they met the established objectives. When comparing the alternatives (Step 5) using effectiveness, efficiency, acceptability, and completeness as a guide, the study team was able to screen out an alternative because it did not meet flood risk management objectives or the purpose and need of the project. Also, costs for the screened-out alternative far outweighed the benefits. The benefit-cost ratios, impacts to natural resources, reduction in life safety risk, and reduction in uncertainty related to flood risk were considered when comparing the remaining alternatives (USACE Portland District and Columbia Corridor Drainage Districts, 2021).

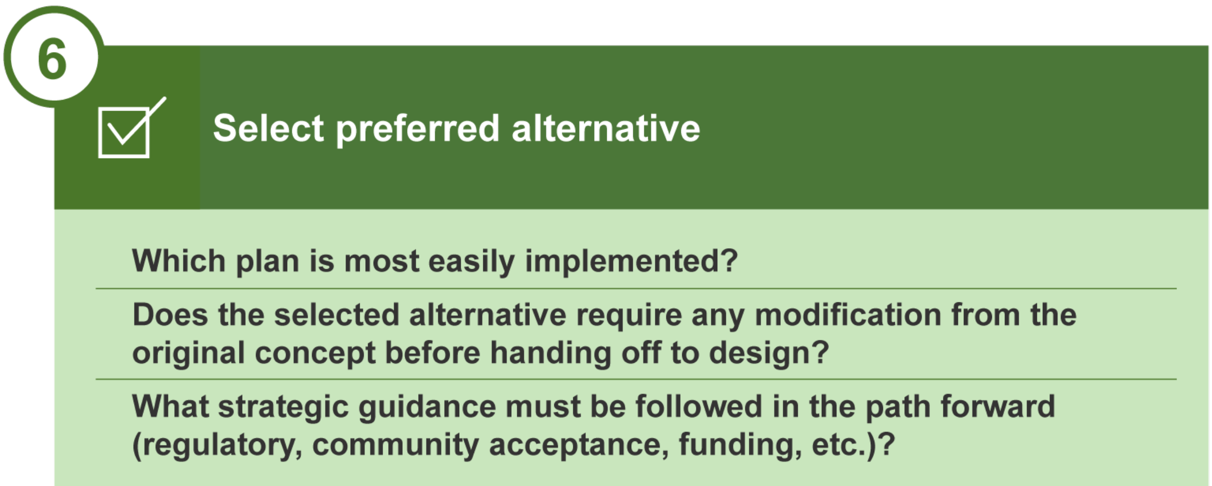
3.6.4 Completeness

Completeness considers the extent to which an alternative provides and accounts for all necessary investments or other actions to ensure the realization of the planned effects. The completeness of each alternative will consider whether necessary components and actions are identified, including the adequate mitigation of significant adverse impacts, and the degree of uncertainty (or reliability) of achieving the intended objectives. If an alternative is found to be incomplete, either measures must be added, or complete reformulation of the alternative is required to achieve all objectives and benefits. If objectives and benefits cannot be achieved, the alternative—or measures comprising the alternative—should be evaluated to confirm whether it is worthwhile to carry forward. If not, the alternative should be screened from further consideration.

3.7 Step 6: Select Preferred Alternative

Selection of an alternative amongst those considered should demonstrate how and why the plan stands out from the other alternatives considered, including a no-action plan. This will include the results of the evaluation (Step 4) and comparison (Step 5) of the alternative plans and justification for the selection (Figure 6-11).

Figure 6-11: Plan Formulation—Step 6



The selection of an alternative should be based on a comparison of the performance of each alternative with the evaluation criteria chosen to measure performance in Step 4 and to compare plans in Step 5. Justification must be presented clearly as to why a specific plan was selected based on its relative performance across the various criteria. In certain situations, even though a project may be technically, economically, socially, financially, and environmentally feasible, other influences, such as political or limited support from the community may limit its ability to be implemented.

STEP 6 EXAMPLE: PORTLAND METRO LEVEE

Once a focused set of alternatives was agreed to by the study team, and study results compared, the benefits were compared to the project costs. Benefit-cost ratios were calculated, where the benefits (in dollars) are divided by the costs to get a “ratio.” All alternatives had a benefit-cost ratio above 1.0. However, the alternative that was ultimately selected had the lowest benefit-cost ratio but the greatest annual net benefits. It was rated highest in terms of the extent to which the objectives were met, and the net benefits provided more uniform flood risk reduction throughout the study area, especially in areas that met definitions for environmental justice considerations, and provided the greatest reduction in life safety risk (USACE Portland District and Columbia Corridor Drainage Districts, 2021).

4 Best Practices and Considerations

Best practices outlined in these guidelines should be followed throughout the entirety of the levee formulation process described in section 3. Additional considerations, which may be general in nature or project-specific, may need to be taken into account during individual steps of the planning process. This section outlines best practices and other considerations associated with formulating a levee project.

4.1 Managing Risk

4.1.1 Life Safety

One of the overarching principles of these guidelines is to hold life safety paramount. Accordingly, a primary best practice is to formulate levee projects with a focus on human life while taking into account all potential failure modes. As discussed in **Chapter 4**, factors that influence life loss include, but are not limited to, the depth and velocity of flooding, levee performance, socio-economic characteristics of the population, warning systems, evacuation plans, emergency response, and other preparedness measures.

Planning for both existing and proposed levee projects requires the evaluation of risks imposed by the levee on the population in the leveed area (levee risk), as well as evaluating the overall flood risk with the levee in place (**Chapter 4**). Quantifying consequences for both existing conditions (no levee) and with a levee in place, will help communities understand any potential adverse or beneficial impacts to life and/or property. Reduction in flood risk should be quantified in terms of project benefits (e.g., reduced consequences, social or environmental benefits) for use in evaluation and comparison of levee alternatives that include varying levee height, alignment, and/or footprint.

Alternatives should be considered in terms of the tolerability of the remaining flood risk and whether or not risks have been managed to be as low as reasonably practicable. The evaluation must consider the specific characteristics of the flood risk and the leveed area, as well as the values of stakeholders (**Chapter 5**).

4.1.2 Levee Superiority for Riverine Levees

Levee superiority is the concept of designing portions of the levee at higher elevations except in a location where initial overtopping is desired and can occur in a more predictable fashion. The best practice is that, where feasible and practical, levees should be designed and constructed with locations where overtopping can be controlled. Levee superiority can be included in the design of a single levee or within a systemwide setting.

Should overtopping or a breach occur as a result of flooding, the breach is more likely to initiate at the intentionally designed location, providing opportunities for more orderly floodplain evacuation and reduced reconstruction requirements (time and cost) after a breach. The surface protection of the levee at the designated location can also be reinforced to reduce the likelihood of breaching.

More complex scenarios for assessing levee superiority might include the following:

- Locations where two separate levees exist across the river from one another—one surrounding highly urbanized areas, the other mostly agricultural area, but both having similar levee elevations. Through risk-informed decision making, the levees could be modified such that overtopping into the agricultural area occurs before the urban area to reduce potential life loss consequences. Note that this option for levee superiority would require extensive collaboration and engagement with all affected landowners and other stakeholders.
- Locations where there are adjoining but independent levees and there is a potential of a ‘chain failure,’ whereby the breach of one levee may trigger the breach of the next. In this situation, levee superiority may involve the provisions of relief structures at the upstream end of the adjoined systems.
- Locations where flank or tie-back levees exist along tributaries to the river. The hydrology for the tributary may provide higher water surface profiles than a river, or the tributary may be flashy with short warning times and potential dangers from quick overtopping. Superiority of levee crest levels along the tributary reaches over those for the mainstem reaches may be appropriate. For long or complex levee systems, multiple overtopping reaches should be considered.
- Locations where there are embedded structures such as gravity drains, pump stations, and closure structures. Here the superiority approach would be to provide for increased crest elevations for 100 to 150 feet immediately upstream and downstream of the embedded structure to avoid overflow around and into the structure and any resulting damage.

Water surface profiles, distribution of overtopping volumes, and evaluation of the subsequent consequences are needed to understand where overtopping sections should be located so that overtopping initiates at the least vulnerable location where impacts of flooding are the least damaging. Documenting overtopping consequences in the leveed area is an element of the flood risk management strategy, along with emergency action plans and local flood warning systems.

Decisions regarding overtopping locations should consider risk transfer and risk transformation. It is also important that with reasonable confidence, the overtopping location be designated and maintained for the life of the levee.

4.1.3 Risk Transfer and Transformation

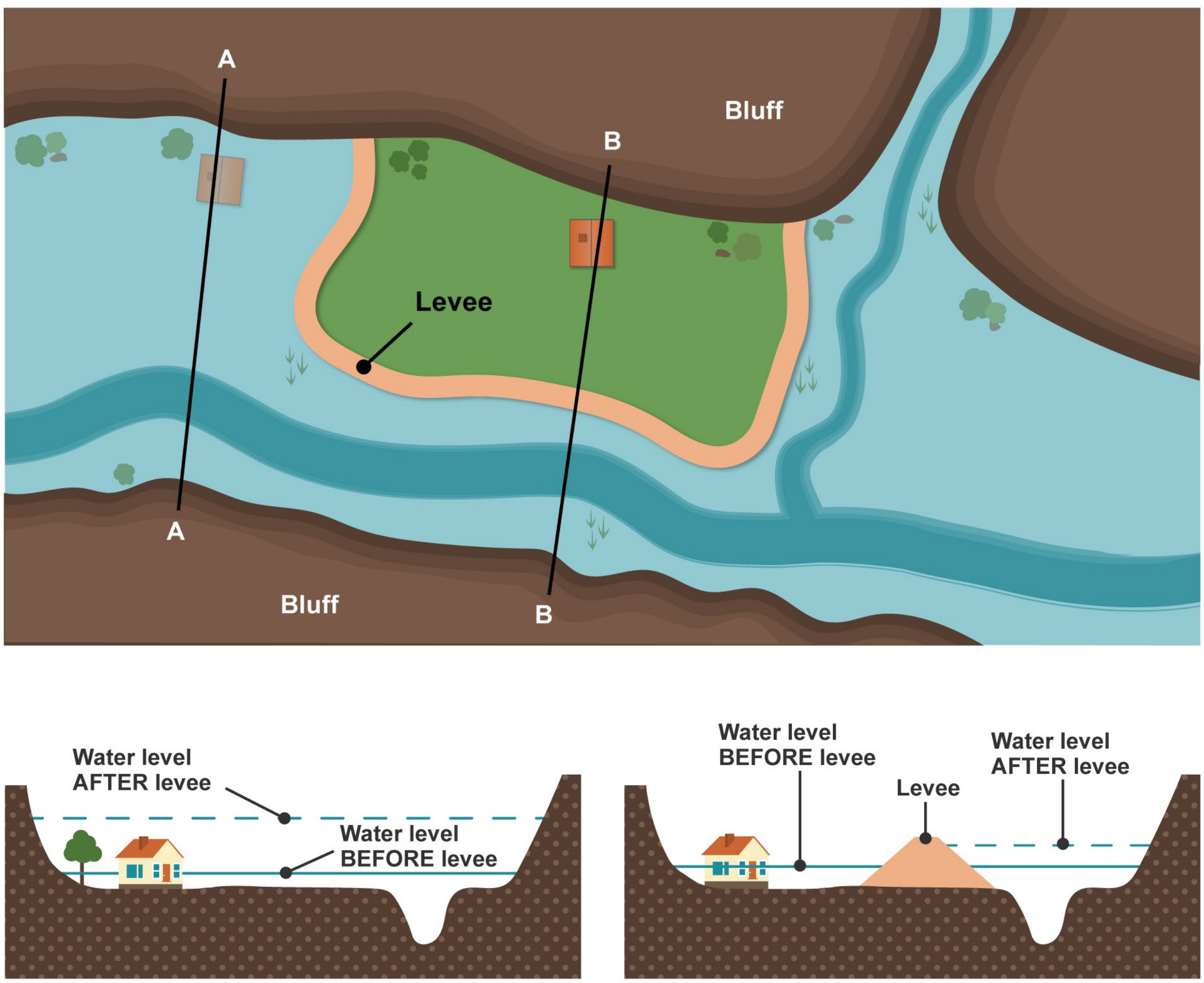
Risk transfer occurs when an action shifts flood risk from one area to another. As shown in Figure 6-12, a new levee narrows the river channel and may cause elevated water levels upstream (represented by Section A-A in the figure) and along the levee (represented by Section B-B in the figure). The levee may also cause higher flow velocity along the opposite bank (bluff) that could induce erosion and impact adjacent properties.

Risk transfer should be avoided or mitigated. For example, setting back a levee from a river channel can minimize impacts to channel flow capacity, potentially preventing or minimizing the transfer of flood risks to areas outside of the leveed area.

Risk transformation occurs when risk is altered as a result of changed conditions, including mitigating another risk. For example, flood risk in the presence of a levee is different than without a levee. Prior to levee construction, flooding happens gradually at the rate of rise of the flood source. With a levee in place, levee breach can occur suddenly, potentially leading to increased life safety risk. In addition, construction of a levee often encourages development within the leveed area. Increased population within the leveed area would transform the risk (i.e., increase the risk). Nonstructural flood risk management measures like evacuation planning and land use planning are needed to address the increased risk associated with an increase in population.

The best practice is to minimize or mitigate for risk transfer and to recognize and address risk transformation in the planning and design process. The impacts of risk transference and/or transformation should be assessed during the formulation and evaluation of alternatives since these impacts could result in an infeasible project.

Figure 6-12: Transfer of Risk



Section A-A looking downstream

Section B-B looking downstream

4.2 Social Considerations

4.2.1 Collaboration and Engagement

From scoping a potential project and formulating alternatives to selecting a viable plan, collaboration and engagement is necessary at all levels and stages of the planning process.

During scoping, engaging with community members and leaders can help identify problems and opportunities that may not be readily apparent when formulating a levee project. Problems such as flooding in certain areas and the social/economic/environmental impacts, as well as opportunities such as incorporating recreational features that benefit the community or reducing the potential impact of a project on landowners.

Those that live within the impacted community may view issues from a different lens than those that study and propose mitigation measures. By understanding the problems and opportunities as identified through the experiences of community members, the planning team will be less likely to screen out viable measures or alternatives that might better fit a community's needs during the plan formulation process.

The planning team should incorporate a variety of opportunities to engage with community members at different points during the plan formulation process. When communities are engaged throughout the entire planning process, there is a better chance for support of the project. In addition to scoping the work, numerous opportunities to engage with community members exist during plan formulation. Engagement is especially important during the comparison of alternatives and plan selection. When communities are engaged throughout the entire planning process, there is a better chance for support of the project. Additional information on engagement is included in **Chapter 3**.

4.2.2 Social Equity

When planning a levee project, it is important to identify underserved communities that may be disproportionately impacted by flooding—due to the absence of resources, remnants of historically discriminatory policies or continued marginalization—and work to build social equity so that everyone has an equal opportunity to meaningfully participate in the levee formulation process (Table 6-4).

Table 6-4: Social Equity Considerations

Factor	Questions to Ask
Equitable distribution of social, environmental, and economic costs and benefits of a project.	• What are the costs and benefits? • To whom are these being distributed? • What are the group-based differences in costs and benefits?
Recognition and acknowledgement of historical injustices and/or present-day vulnerabilities related to the project.	• Is there a historical and/or current-day context of disproportionate costs and benefits related to past projects? • Is this context being recognized in the current project? How so? • Are impacts to all potentially affected groups being considered?

Factor	Questions to Ask
Equitable participation in decision-making processes for the design, construction, and O&M of the project.	• Have all potentially affected groups been identified as stakeholders in the project? • How and to what degree are each of these groups involved in the project processes and decision making?

Federal, state, and local agencies have either developed, or are developing, policies to support equity as part of flood risk management strategies and should be referenced when formulating a levee project. These policies could provide for:

- Availability of current mapping tools that help identify and distinguish those communities that traditionally have been disproportionately or adversely impacted by flood risk hazards.
- Requirements for engagement.
- Proportion of benefits allocated to certain communities.
- Regulatory requirements for identifying potential effects and mitigation measures in consultation with affected communities (U.S. EPA, 1969).

4.2.3 Underserved Populations

According to a recent study analyzing data from the National Levee Database (NLD) and the Climate and Economic Justice Screening Tool[1] (Vahedifard *et al.*, 2023), results indicated that a substantially larger number of communities who live behind levees across the nation are considered disadvantaged in terms of race, education, poverty, and disability. In addition, flood risk, whether in a leveed area or not, tends to negatively impact historically underserved and socially vulnerable communities disproportionately, as they often have fewer resources to recover from a major flood event.

When planning for a levee project, whether building a new levee or rehabilitating or modifying an existing levee, it is important to consider anyone who may be negatively impacted by the proposed project, especially underserved populations. For example, will construction of a new levee cause the displacement of low-income, mobility restricted, or unhoused populations? If the potential exists, it is important to work with community leaders, trusted community service groups, and those community members to develop a plan that will lessen the impacts. This could include options to move the levee alignment or establish a relocation plan (rather than resort to forced displacement) that provides resources and financial assistance to help those community members move out of the project area.

Planning for a new levee or rehabilitation or modification of an existing project could present an opportunity to begin developing a public engagement strategy and incorporating it into the planning process. Underserved communities living behind levees often lack (1) awareness about the importance of levees and the role they play in reducing flood risk, as well as the risks associated with living behind a levee, and (2) resources to adequately maintain the levee.

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[1] Climate and Economic Justice Screening Tool: https://screeningtool.geoplatform.gov/en#3/33.47/-97.5.

Increasing knowledge and awareness of levee benefits and risks is a critical first step in building more resilient communities. The positive outcomes from increasing community knowledge and awareness of levees are discussed in greater detail in **Chapter 3**.

4.3 Pursuing Additional Benefits

4.3.1 Co-Benefit Opportunities

In addition to the primary purpose of flood risk reduction, levees can provide important social, cultural, historical, ecological, and recreational co-benefits, serving as riverine habitat corridors, regional trails, parks, transportation links, and community infrastructure such as community centers. The best practice is to seek opportunities to introduce or enhance such co-benefits. Examples of potential co-benefits include, but are not limited to:

- Transportation corridors.
- Recreation and tourism.
- Ecosystem and habitat restoration and preservation.
- Water and air quality improvement.
- Replenishing groundwater.
- Climate effects mitigation through carbon storage and sequestration from added vegetation.

Co-benefit opportunities should be considered in Step 3. In Step 4, the evaluation of alternatives with co-benefits should be handled differently than those alternatives with a single purpose. For example, a multi-criteria decision analysis could be utilized to incorporate multiple layers of benefits across varying categories, as opposed to single purpose projects with a primary benefit.

To evaluate co-benefit opportunities, use a multi-disciplinary team and multi-criteria decision-making tools, with the understanding that not everything can or should be quantified or monetized. Some benefits—such as damage reduction to structures—are more straightforward to quantify and monetize. However, other benefits, such as ecosystem services, environmental justice, or improvements to community resilience are not. Experts in these areas can supplement the planning team by helping to identify the associated benefits for consideration. Benefit-cost analysis has limitations and should not be the only metric considered in evaluation and comparison of alternative plans. Decisions should be informed by, but not based on numbers. Further, it is important to link decisions with an understanding of the benefits and impacts.

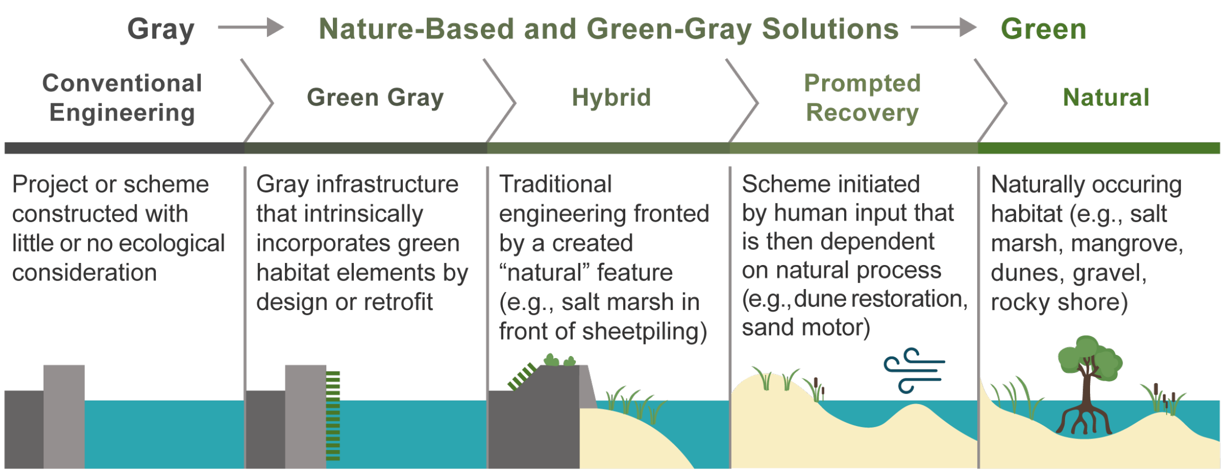
4.3.2 Natural and Nature-Based Solutions

If the levee cannot be set back from the channel to benefit floodplain function, the levee should be designed to incorporate vegetation to recover some amount of floodplain function or maximize environmental benefits. The best practice is to formulate levees with a holistic approach that incorporates and balances structural elements with natural and nature-based designed features to reduce flood risk, while preserving, restoring, and enhancing ecosystems.

The term **natural and nature-based features** in relation to levees refers to the use of landscape features to enhance environmental benefits, while retaining flood risk management benefits. These landscape features may be natural (produced purely by natural processes) such as beaches, dunes, wetlands, reefs, and islands, or nature-based (produced by a combination of natural processes and human engineering) including such features as planting berms or planting benches. The creation or modification of a levee also provides opportunities for ecological enhancement and redundancy in flood risk reduction. In the context of levees, this may range from simple additions to conventional levees (embankments and floodwalls) to major environmental engineering where the levee just exists as a backstop final line of defense after much of the hazard has been dissipated by ecological measures (Figure 6-13)[2] (Brill *et al.*, 2021).

Natural and nature-based features provide opportunities to develop solutions with co-benefits that incorporate both direct benefits, such as reducing erosion, to diverse co-benefits valued by the society. Examples of co-benefit opportunities are listed in section 4.3.1. Incorporation of natural and nature-based features is considered in Step 3 as a measure to include within an alternative.

Figure 6-13: Continuum of Nature-Based Approaches



A balanced combination of measures could include, in addition to levees, the use of floodplains, floodways, and natural ecosystems for rerouting and storing floodwaters and incorporating natural marshes and wetlands to reduce storm surge, waves, and/or flow velocity. Natural and nature-based features can provide many positive benefits to flood risk reduction and environmental enhancements. Common natural and nature-based features vary based on the type of environment where the levee will be constructed and can include:

- Coastal environments:
  - Beaches and dunes (dissipate waves and reduce erosion).
  - Coastal wetlands (flood protection and erosion control).

[2] Figure adapted from the *International Guidelines on Natural and Nature-Based Features for Flood Risk Management.*

  - Reefs (dissipate waves).
- Riverine environments:
  - Reconnecting floodplains (reduces runoff, slow flow, and decrease peak discharges by retaining and restoring water).
  - Removing obstacles or providing secondary channels (increased conveyance capacity).

In river systems, restored floodplains can store and convey water, and upland forests can help slow and retain runoff, reducing flood loading on the levees. In many coastal areas, naturally occurring habitats and geographic features can provide some protection from the coastal processes and storm events. The main habitats involved in nature-based solutions for coastal levees are tidal salt marshes, mangroves, maritime forests, coral and shellfish reefs, beaches, and dunes. Flood risk reduction is achieved through (storm) water absorption through infiltration, flood storage, or wave and surge attenuation. For example, the sloping nearshore bottom of beaches causes waves to break and dissipate wave energy across the surf zone. Similarly, dune fields are physical barriers that reduce inundation and wave attack on the inward side of the dune. Landscape features can help to build and stabilize shorelines and riverbanks, thus reducing erosion.

Ecosystems can be a significant source of resilience for levees. When formulating a levee project, the team should consider ecosystem processes in order to provide enhanced capacity to deal with uncertainties and unexpected events. Natural features are often more resilient than human-made infrastructure because they adapt more readily to changing conditions such as sea-level rise or land subsidence. Because the building blocks of natural and nature-based features are natural (e.g., sediments and plants), the environment itself is a source of natural resupply and repair. For example, existing or restored sediment transport processes could be sufficient to sustain a natural island or wetland that is providing flood risk reduction value. The adaptability of landscape features as flood risk reduction measures provides value with respect to uncertainties. For example, an island that is enhanced or constructed to attenuate storm surge and waves for a community could be expanded if experience and evidence indicate that expansion can increase flood risk reduction benefits.

The International Guidelines on Natural and Nature-Based Features for Flood Risk Management (Bridges *et al.*, 2021) provide practitioners with guidance on the conceptualization, planning, design, engineering, construction, and maintenance of nature-based solutions to support flood risk management projects. It is important to consider using natural and nature-based features as part of the flood risk management strategy. However, alternative features must meet the intended objectives, so striking a balance between operational watershed management and any potential nature-based solution is also important.

4.3.3 Climate Resilience

Climate change impacts on coastal or riverine levees and on internal drainage systems behind levees are significant risk factors that should be addressed in planning and design as a best practice. Impacts of climate change will differ across the country and those impacts that have the potential to affect the project planning area should be identified.

Climate change risks cannot be evaluated based on past events alone, but will require special predictive studies covering the levee lifecycle. The quantification of this risk and incorporating climate change risk reduction and resilience measures in levee design, modification, or rehabilitation are important considerations that should not be overlooked or underestimated. Quantification of climate change impacts should be considered in Step 2 where future conditions are forecasted.

Some federal and state regulatory agencies have completed climate change studies for planning purposes on actual projects. These studies may provide the guidance needed for a new project in the region or examples of how the study should be performed. A funding agency may require existing study results be applied or specify how climate change analysis is to be performed and applied as a condition of funding the project.

CLIMATE CHANGE CASE STUDIES

The U.S. has experienced significant weather shifts over the last decade in ways that place levees at risk. Levee owners, operators, regulators, and design professionals must understand the shifting trends in regional climate threats and manage levees with consideration of these rapidly evolving conditions. While climate models have advanced, they produce different results, as each has its own assumptions and methodologies for representing local, regional, and global climates. This makes planning for levee projects challenging. Case studies where climate science has been used in the levee formulation process are provided below.

- The U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/case-studies) provides a library of case studies to show how people are building resilience in their communities.
- The California Department of Water Resources' Central Valley Flood Protection Plan is California's strategic blueprint for Central Valley flood risk management. The 2022 Update focused on climate change and how to plan a resilient flood system for the future. The study looked at projections of increased warming, extreme precipitation, changes in flood magnitudes and frequencies, and overall changes in timing, duration, and magnitude of flows (California DWR, 2022).
- The city of Richmond, California, examined a broad spectrum of the community's climate change vulnerabilities and looked to prioritize adaptation responses based on the greatest risks and needs. The outcomes were used to inform planning efforts to reduce overall flood risk (City of Richmond, 2016).

4.3.4 Adaptive Management

Levee projects are set within the natural environment and, when working with nature, the best practice is to expect change and manage adaptively. Adaptive management is a multi-step, iterative process for adjusting management measures to changing circumstances or new information about the effectiveness of the project or the system being managed. Adaptive management addresses uncertainty through phased project implementation. It introduces the ability to make adjustments to the project throughout its lifecycle to meet or improve expected outcomes and benefits. It allows phasing of projects—instead of needing to minimize uncertainties up front—and provides flexibility to change direction or adapt the overall strategy.

Adaptive management can aid levee formulation and design by avoiding overbuilding to account for uncertainty. It saves cost by not overdesigning up front, while providing the ability to adapt the design over time, as needed, sustaining project life span and benefits. It can also be applied to handle design uncertainties and actual performance post-construction, to adapt with real-time data as they are being gathered. Overall, the process can reduce lifecycle project costs, reduce the risk of failure, improve outcomes, allow an expansion of knowledge for decision making, and optimize O&M costs over time.

To maximize benefits derived by adaptive management, its applicability to specific levee project conditions and needs should be considered as part of the levee formulation process based on the following three conditions (Rist *et al.*, 2013; Williams, Szaro and Shaprio, 2009):

- There are relevant and measurable uncertainties in the outcomes of management actions, or the system being managed.
- The project is controllable, allowing for future modifications in management actions.
- There is a low risk of irreversible harm to the environment or society (compared to no action).

Adaptive management should be considered in:

- Step 2: Current and future conditions will dictate the magnitude of adaptive management needed for an alternative.
- Step 3: Adaptive management measures should be included in formulation of alternative plans.

An example of adaptive management is the consideration of climate change in levee design. While much definitive work has been performed recently in understanding climate change, large uncertainty remains in forecasting future conditions, as climate science continues to evolve. Levees have a long, often indeterminate, lifecycle and climate change presents a dynamic condition that may not be fully understood. Moreover, it may be infeasible to finance a measure that is formulated around a conservative estimate of climate change projections, or the term required to finance and construct such measures may be so lengthy as to present unacceptable interim risk to the impacted community. Thus, an adaptive management strategy could be purchasing adequate right of way and designing levee features to accommodate modifications to address future conditions.

4.4 Considerations for All Alternatives

4.4.1 Laws, Legal Requirements, and Regulations

Many states, federal agencies, and local governments have water resource setback laws, more commonly known as riparian buffer strip laws. These laws often restrict the types of activities that can be conducted within a designated distance of the watercourse. Representatives from state regulatory bodies often serve as the best resource on state laws and implementing guidance on any other legal requirements. Planning and permitting departments should be engaged early to understand regulations and restrictions on construction of the project, timing to acquire needed permits, typical needed mitigation elements, and fees. Additionally, engaging with and gaining support from state and local governments can help ensure the project will move forward, rather than facing delay due to a denied permit.

4.4.2 Environmental Impacts and Regulatory Compliance

The best practice is to minimize potential impacts from a levee project on environmental, natural, and cultural resources, and develop a mitigation strategy in the event that certain impacts are unavoidable. Adhering to regulatory processes and obtaining required permits is critical to advancing a project to the design and construction phases. Determination of which regulations are in need of compliance is often dictated by the funding used. Federally funded projects are required to follow the National Environmental Policy Act process as described in the callout box.

NATIONAL ENVIRONMENTAL POLICY ACT REQUIREMENTS FOR FEDERALLY FUNDED PROJECTS

The National Environmental Policy Act process requires an assessment of potential environmental impacts caused by the project and several alternative approaches to be evaluated. The key elements of that process include:

- Determining the project's purpose and need and the range of alternatives to be considered, including the no action. Identifying potential environmental impacts.
- Coordinating with relevant agencies including federal, state, local, tribal (if applicable), and others as necessary.
- Involving the public.
- Identifying mitigation for unavoidable impacts.
- Documenting the analysis and decisions (defined further below).

The National Environmental Policy Act also requires either an environmental assessment or environmental impact study before the levee construction project begins. These submittals are often completed during the formulation phase of a project. Typically, one of three different levels of analysis and documentation will be required: (1) categorical exclusion; (2) environmental assessment; or (3) environmental impact statement.

A federal action may be categorically excluded from a detailed environmental analysis if the proposed work does not have a significant effect on the environment. If a categorical exclusion does not apply, an environmental assessment may be required. Environmental assessments are intended to include a brief discussion on the purpose and need of the proposed project, alternatives analyzed, environmental impacts of the proposed alternatives, and a listing of agencies and persons consulted. If significant impacts are anticipated by the proposed project, an environmental impact statement may be required. An environmental impact statement is more detailed and the effort to produce it is more rigorous than an environmental assessment.

Other state and local processes and permits should be investigated and reviewed during formulation of a levee project, as described in the regulatory processes/permits callout box.

These assessments and studies will help inform levee formulation and construction activities to minimize and reduce impacts to environmental and natural resources. The results of these efforts should be thoroughly integrated into the construction documents for the levee project such as the details of easements, access, construction techniques, construction working seasons and hours, and construction materials. Any environmental considerations on the site that need to be protected by the constructor—or that may necessitate special working arrangements—are commonly identified in the environmental assessment and included in the construction document.

Regulatory permit requirements and associated procedures are in place to ensure that if the proposed project impacts existing natural resources (e.g., biological, cultural), those impacts are limited to the extent practical. For unavoidable impacts to critical resources, appropriate mitigation is provided. Activities related to regulatory compliance touch every phase of the formulation, design, and construction process.

EXAMPLE OF REGULATORY PROCESSES/PERMITS

Some federal and state agency permits and reviews that should be anticipated during formulation of levee projects include:

- **National Environmental Policy Act**: Applies to discretionary projects that are funded, authorized, or carried out by federal agencies.
- **Clean Water Act Section 404 and Rivers and Harbors Act Section 10**: Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged material or placement of fill material into waters of the U.S., including wetlands. Section 10 of the Rivers and Harbors Act requires approval prior to the accomplishment of any work in, over, or under navigable water of the U.S.
- **Endangered Species Act Section 7 Consultation**: The Fish and Wildlife Coordination Act requires federal agencies that permit or license water resource development projects to consult with the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the appropriate state wildlife agencies regarding potential impacts on fish and wildlife resources and measures to mitigate those impacts.
- **Magnuson-Stevens Fishery Conservation and Management Act**: If a project has the potential to impact essential fish habitat, the lead federal agency should consult with National Marine Fisheries Service and conduct Section 7 consultation.
- **National Historic Preservation Act Section 106**: Section 106 accounts for the effects of actions on cultural resources listed in, or eligible for listing in, the National Register of Historic Places.
- **State, regional, and local jurisdictional environmental permits**: State departments of fish and wildlife, water quality control, and other local agencies may have regulatory pathways that will need to be completed before construction. In addition, local jurisdictions are likely to have regulatory pathways and requirements that will need to be followed for levee construction projects.

This list is not exhaustive and appropriate permitting specialists should be included on the project team.

Prior to the onset of the planning phase, federal, state, and local permit requirements should be identified in conjunction with an approach that conforms to the regulatory requirements. Consultation with key agencies and tribal nations should also be initiated early in the process to confirm regulatory constraints and specific requirements. Getting multiple agencies and tribal nations in the same initial consultation meeting may be helpful to build consensus around appropriate fish and wildlife requirements and to strive for consistency of project specific regulatory input. Federal and state fish and wildlife agencies have specific requirements that should be incorporated into the planning and design of ecosystem restoration components of a levee project.

4.4.3 Work Within Existing Floodplain Management

The best practice is to align levee project formulation with watershed floodplain management, flood risk management strategies, community development plans, and land use decisions throughout the planning and design process.

Project formulation activities aligned with existing floodplain management efforts are particularly important during the following planning steps:

- Step 1: Existing floodplain management strategies or requirements associated with designated floodplains or floodways may result in the formulation process.
- Step 3: Formulation of alternative plans should be cross-referenced with other plans, laws, and regulations, as applicable, to ensure compatibility.
- Step 6: The ability of an alternative to be compliant with existing floodplain management requirements may hinder or enhance selection of that alternative.

The best practice is to be aware of, recognize, and align levee project formulation with existing floodplain management or flood risk management strategies and requirements. The Federal Emergency Management Agency (FEMA) is the federal agency responsible for administering the National Flood Insurance Program. This program is intended to help property owners recover more quickly and at less cost post-flood. Additional information on the National Flood Insurance Program is provided in the callout box in section 4.4.4.

Most states and many communities also have hazard mitigation plans, which should also be a consideration during project planning. State hazard mitigation officers and local or county floodplain managers are good resources to engage early in the formulation process. In addition, the local FEMA regional office can assist in providing additional information.

4.4.4 Cost and Funding

A best practice critical for project success is preparing a funding strategy for the lifespan of the levee and to consider all potential costs associated with the project. Community leaders and stakeholders must agree to and plan for funding sources and management of funds. Project funding strategies can vary greatly and may include any combination of a local, state, or federal cost share.

Levees typically need to meet some test of economic viability over the period of economic appraisal—typically in the range of 50 to 100 years. Sometimes, identifying multiple potential functions for levees and co-benefits can attract additional funding from other partners and allow an improved multi-functional concept to be developed. Several grant programs exist to support funding of levee projects. Existing state or local hazard mitigation plans should be reviewed to ensure compatibility with the proposed project.

Project formulation activities aligned with cost and funding should be considered during the following planning steps:

- Step 1: Limited funding for initial and long-term costs over the life of the project can be a constraint.
- Step 3: Preliminary costs may help screen out measures in initial plan formulation.
- Step 4: Costs for the levee project and anticipated funding resources for future costs may limit scoring for an alternative.
- Step 6: Costs and funding sources may impact the selection of an alternative.

NATIONAL FLOOD INSURANCE PROGRAM

The National Flood Insurance Program provides flood insurance from potential flood damage for personal property, residential properties, and non-residential properties. Communities can participate in the National Flood Insurance Program if they agree to adopt and enforce floodplain ordinances that reduce flood risk. Each state or community that participates must adopt the minimum National Flood Insurance Program requirements or can enforce more stringent requirements. It is important early in the formulation process to understand if the state and community participate in the National Flood Insurance Program and what specific related requirements have been adopted.

As part of the National Flood Insurance Program, FEMA develops flood insurance rate maps, which are officially adopted by the participating community, for both establishing the flood insurance rates and floodplain management activities. Rate maps should be reviewed to understand already established areas of potential flood risk, limitations on construction within a special flood hazard area or floodway, and how the project may alter this existing information. Note that these rate maps are updated frequently; therefore, the project team should research the latest available flood insurance studies, resulting mapping, or if map revisions are currently underway. The project formulation team should avoid floodways already depicted on flood insurance rate maps when considering levee alignments. If avoiding a floodway is not feasible, the formulation team should work with FEMA to determine necessary actions.

National Flood Insurance Program requirements will include limits on changes to the floodway and flood risk transfer. The floodway is the channel of a river or watercourse and the adjacent land areas that must be reserved in order to discharge the 1% flood event or base flood, a requirement of the National Flood Insurance Program. There also may be land use restrictions for areas that have been subject to reoccurring flooding. In addition, the National Flood Insurance Program has specific processes for the consideration of levees. Different areas, such as the floodway, are depicted on these maps. The existing flood insurance rate maps are a good starting point to understand any impacts the levee project may have on the National Flood Insurance Program regulations.

Once a levee project has been constructed, communities can request a letter of map revision to depict the effects the levee has on flood risk. Letters of map revision are generally based on the implementation of physical measures that affect the hydrologic or hydraulic characteristics of a flooding source and thus alter the flood risk. Through this process, a community's flood risk is reevaluated with the levee in place, floodplains depicted on flood insurance rate map panels are revised, and flood insurance needs are reassessed.

4.4.5 Operations and Maintenance

The risk of levee failure, potential associated consequences, and recovery costs increase without proper O&M of a levee system. Therefore, the best practice is to invest in proper levee inspection, maintenance, and repair. An additional best practice is to define expectations for long-term levee O&M, including required technical capabilities and funding. **Chapter 9** provides guidance on operating and maintaining a levee.

Project formulation activities aligned with O&M should be considered during the following planning steps:

- Step 1: Limited resources for proper O&M (staffing and cost) over the life of the project can be a constraint.
- Step 5: Factors such as effectiveness and efficiency may be influenced by the ability to provide proper operations and maintenance for a project. For an alternative to be effective, it needs to significantly contribute to the solution of the problem. For an alternative to be efficient, it must be cost effective. Lack of a proper O&M strategy makes effectiveness and efficiency challenging, as degradation of the levee without proper O&M would impact both.

- Step 6: Costs for O&M may impact selection of an alternative.

Adequate space should be allowed for maintenance, inspection, patrolling during flood inspection, and floodfighting. O&M requirements, including inspection and emergency operations (floodfighting), should be included in the geometric design. For example, the steepness of a levee slope may need to be limited to allow for safe mowing operations. Also, O&M requirements may require widened turnaround areas on the crest, as well as periodic ramps spaced along the levee alignment, connecting the crest to the levee toe for access and emergency operations.

Since O&M requirements may influence the selection of a preferred alternative—expectations for levee O&M along with costs and funding sources—should be outlined and agreed to as part of the levee project formulation. Questions to consider include:

- Who is responsible for conducting the O&M of the levee?
- Does the responsible party have the appropriate funding and resources for a proactive, ongoing long-term O&M program?
- What are the maintenance expectations? For example, does the levee need to be well manicured or can it be left more natural to create wildlife habitat? Does the levee need to be maintained for public safety if used for recreation, or is it in a rural area where this is not a concern?
- Does the levee require active operation (e.g., closing road closure structures or installing demountable floodwalls) and does the responsible party have capacity and capability to operate the levee in a timely manner?

4.4.6 Documentation

Throughout project development (i.e., all steps of the planning process), important data, computations, and engineering and scientific management decisions should be well documented as a best practice. The required level of documentation will depend on the project's size, regulatory requirements, and potential impacts to health, safety, and the environment.

The project documentation system or repository should be established at the onset of the project, with all relevant background information and data organized appropriately. It is a best practice to assemble spatial data into a geographic information system (GIS) database for ease of visualization, usage, and manipulation, as shown in Figure 6-14.

Figure 6-14: GIS Documentation for Spatial Data

The National Levee Database, developed and maintained by the U.S. Army Corps of Engineers (USACE) and FEMA, with collaboration with federal, state, and local governments, captures all known levees in the U.S. The database includes the location of levees, people and assets behind a levee, responsible entity, and other information related to levees. It provides users with the ability to search for specific data about levees and serves as a national resource to support awareness and preparedness around flooding. The NLD houses information that should be reviewed (if available) for any levee project during the formulation process.

Any field reconnaissance during the planning phase and site characterization and investigation during the design phase should be added to the documentation repository, with clear references for the data or information source. This will allow easy access to all relevant data from the planning, design, and regulatory team members to feed into design analyses and regulatory impact assessments. During design, all data, project plans, and specifications should be added to the repository as the project progresses through conceptual, feasibility, and final design. During construction, the project documentation system may be updated and refined to meet the needs of construction documentation, as outlined in **Chapter 8**. Alternatively, it is not uncommon for the construction bid documents to require the contractor to develop their own document management system. If that is the case, certain background or baseline condition documents and data will need to be transmitted to the contractor.

4.5 Site Specific Considerations

4.5.1 Land Use

Past, current, and planned future land use can influence the planning and design of a levee project as summarized in Table 6-5; therefore, the best practice is to research any potential changes in land use and communicate this to the planning and design teams. For example, the proximity of existing development may restrict the possibilities for levee alignment. Conversely, changes in land use in the watershed could influence stormwater runoff characteristics and the resulting loading on the levee or interior drainage requirements.

In undeveloped areas such as forests and grasslands, rainfall and snowmelt collect and are stored on vegetation, in the soil column, or in surface depressions. When rainfall intensity exceeds the ground's infiltration capacity, or the rate at which soil can absorb surface water input, runoff occurs. However, in winter months when the ground is frozen or saturated from rain events or snowmelt, overland flow infiltration is limited, and runoff can occur more quickly.

Similarly in urban areas—where much of the land surface is covered by roads and buildings—there is less capacity to store rainfall and snowmelt. Construction of roads and buildings often involves removing vegetation, soil, and depressions from the land surface. The permeable soil is replaced by impermeable surfaces such as roads, roofs, parking lots, and sidewalks that store little water, reduce infiltration of water into the ground, and accelerate runoff to ditches and streams. Even in suburban areas, where lawns and other permeable landscaping may be common, rainfall and snowmelt can saturate thin soils and produce over land flow, which runs off quickly. Dense networks of ditches and culverts in cities reduce the distance that runoff must travel over land or through subsurface flow paths to reach streams and rivers. Once water enters a drainage network, it flows faster than either over land or subsurface flow.

Existing infrastructure features, such as public roads and railroads, may influence the levee alignment or features. In some cases, the levee alignment may run perpendicular to roads or railroads and will need to be designed to permit vehicles and trains to pass through. This situation will require specific considerations for levee operations, inspections, construction schedules, evacuation planning, and testing of closures.

In other cases, it may appear convenient to tie a levee alignment into an existing embankment or use an existing embankment as part of the levee alignment. This should only be done if it can be confirmed that the existing embankment—which was not originally designed to serve the purpose of a levee embankment—can be analyzed, improved, and operated for the purpose of flood risk management. Otherwise, using existing embankments as part of the levee alignment should be avoided. The transportation agency, railroad company, or owner of an existing embankment should be consulted early in the planning phase to alert them about the project and to help identify barriers that may influence the proposed levee alignment or design.

Most importantly, land use decisions directly impact what will be in harm's way if a levee were to breach. Development in the leveed area could increase potential consequences associated with levee breach or misoperation, thus elevating levee risk. This potential should be considered when planning a levee.

Project formulation activities aligned with land use should be considered during the following planning steps:

- Step 1: Limited land availability can be a constraint.
- Step 2: Current and any anticipated changes in future land use must be understood through research in this step.
- Step 3: Information collected in Step 2 will inform formulation of alternative plans.

Engagement of community members in the levee formulation process—population at-risk in the leveed area, as well as community officials and entities responsible for the land use decisions and success of the proposed project—is critical for building awareness of the benefits and risks associated with the levee and informing land use decisions. To be effective, these discussions require coordination and planning at the watershed level to ensure that flood risks are not unfairly shifted from one community to another.

Table 6-5: Land Use Types and Influences on Planning and Design

Land Use Type	Influences on Levee Planning and Design
Past	• The presence of cultural resources, ordinance, and contamination may affect project acceptance/approval, design, cost, as well as pose issues during construction. • Historic utilities may create preferential seepage pathways or hindrances to construction and may require design changes or removal/mitigation during construction.
Current	• May impose right-of-way constraints on levee alignment, footprint, and construction activities. • Influence runoff characteristics of the water shed, impacting the volume and timing of river flows. • Influence shoreline behavior in coastal areas. • As a secondary function, the levee may be used as a travel route, which may complicate future improvement activities.
Future	• Long-term regional development plans for the area may constrain design/layout. • Future development may affect runoff characteristics and the resulting flood loading on the levee and interior drainage requirements. • Future utilities or penetrations may introduce new failure modes to the levee. • Future development increases the population and structures to be protected, and so may affect selection of flood risk reduction strategy and levee modification.

Note to table: Adapted from The International Levee Handbook (Eau and Fleuves, 2017).

4.5.2 Right of Way

It is important during the planning process to identify the access corridor required by the entire levee alignment. The **access corridor** is the area needed for maintenance, inspection, and floodfighting and to provide additional room in the future for levee improvements. Providing an access corridor allows for a buffer between the levee and any adjacent land activities reducing potential impacts. Acquiring the needed right of way for a levee can be challenging, especially in urban areas. For example, future development or existing infrastructure often narrow the available space for a levee footprint and the available borrow area. The best practice is to consider the current and future right-of-way requirements as part of alternatives formulation, evaluation, comparison, and selection (Steps 3, 5, and 6). It is a good practice to secure sufficient right of way to allow for construction, planned O&M, emergency response, as well as potential future rehabilitation and modifications. Refer to **Chapter 8** for construction considerations in the right of way.

Within the existing or proposed right of way for a levee project, the location of utilities should be considered. Often the presence of utilities may dictate the alignment of a levee. Before proposing a levee alignment, the local utility department should be contacted to locate all existing and planned utilities. Another site-specific condition to consider may be hazardous, toxic, and radioactive waste contamination. Existing public records should be reviewed, or site testing may need to be considered during the formulation process. Right of way may be constrained by existing structures, political boundaries, environmental areas of concern, acquisition costs, or other factors. These constraints should be identified during planning for all alternative conceptual projects being considered. It is common that for some levees, floodwalls are used in areas that have right-of-way constraints.

In addition to procuring the right of way for levee construction, the following elements should be considered when identifying real estate needs:

- Having adequate room for operation, maintenance, inspection, monitoring, and emergency response activities.
- Having extra space for future expansion of the levee to accommodate design flood criteria changes, changes in hydrology/hydraulic criteria, or to make modifications or rehabilitation for risk reduction.
- Procuring city or county zoning of a strip of adjacent land beyond that required to construct, operate, and maintain the levee to provide a buffer to reduce the impacts of adjacent activities that can endanger levee integrity.
- Procuring temporary easements and rights of entry, as needed, for use during construction to access work and borrow areas.

4.5.3 Easements and Permits

Property surveys should be performed to establish owners of potentially affected properties. Real estate impacts will include permanent land acquisition, permanent easements, and temporary easements required to complete the project. These impacts should be assessed in the early planning phase (conceptual, as shown in Figure 6-17), as easement acquisition can be time-consuming. The need for easements and permits should be considered in Step 1 when constraints are identified.

Existing infrastructure crossings potentially affected by the levee or by levee construction should be identified and the applicable permitting agency criteria identified. This could include buildings and bridges, utilities, roads, railroads, culverts, pump stations, and other facilities. These locations can be obtained from existing maps and record plans but should be field verified. In addition, sensitive environmental or cultural areas may be identified, creating design constraints, required permits, or mitigations.

4.5.4 Cultural Resources

Cultural resource assessments should be conducted during the formulation stage of a levee project. These may include historic and prehistoric archaeological sites, historic districts, and built environment resources, including but not necessarily limited to buildings, structures, and objects (Figure 6-15). This may also include traditional cultural properties and sacred sites, including cemeteries, human remains, and features or sites associated with significant events or practices in the traditional culture of an ethnic group. It can be common for levee projects to have cultural constraints; therefore, cultural resources should be investigated in Step 1 when constraints are identified.

Figure 6-15: Example of a Cultural Resource

Archeologists conduct cultural resource surveys to preserve artifacts found at the site of the Rio de La Plata flood damage reduction project in Dorado, Puerto Rico; August 2019.

Levee projects are often located in areas where there were historically early settlements including Native American settlements and burial grounds. Encountering unknown cultural resources during construction can cause significant delays and increase costs. Thus, it is a best practice to properly prepare for incorporating cultural constraints as follows:

- Identify cultural resources that may be present in the levee project area.
- Evaluate the significance of each identified resource.

- Assess the direct and indirect impacts of the proposed levee construction on the resource including visual effects.
- Identify measures to avoid adverse impacts to a significant cultural resource.

Cultural resource assessments are used to help evaluate, assess, and identify measures to avoid adverse impacts and they vary in level of effort based on the historical significance of the area, as well as the size and nature of the levee construction project. These assessments can include conducting literature reviews, record searches, and archaeological and historical surveys of the levee project area. Assessments are often performed by or under the supervision of a qualified archaeologist.

4.5.5 Interior Drainage Requirements

Interior drainage is a source of flood risk. Any flood risk reduction project, including levee construction, should include consideration of all flood risks throughout the process. A best practice is to assess the impact of the proposed levee on internal drainage of the leveed area. This can include review of existing drainage plans or analysis of the existing topography to establish the natural drainage patterns. The presence or need for drainage ditches, culverts, and pump stations should also be noted.

Project formulation activities aligned with interior drainage requirements should be considered during the following planning steps:

- Step 1: Interior drainage flooding induced by the levee could be a constraint.
- Step 2: Investigate existing drainage features that might impact levee alignment or geometry needs. Understand future precipitation trends and how they may impact interior flooding.
- Step 3: Measures may need to include levee features to manage interior drainage.
- Step 4: Evaluation of the levee project should include any changes in existing drainage the project might impose and how well any measures address those impacts.

Where this interpretation cannot be completed, additional investigation may be required. **Chapter 7** presents guidance on design of interior drainage features.

4.5.6 Hazardous Materials

The early identification of hazardous, toxic, and radioactive waste will be critical to project planning, because rehabilitation of these materials can add significant project cost and schedule delays. Further guidance can be found in Engineer Regulation (ER) 1165-2-132 (USACE, 1992).

During the project formulation and design, a preliminary waste classification assessment based on the collected site investigation data should be made. However, this assessment may be limited for a number of reasons including:

- The data was collected for site characterization purposes and not for waste disposal assessments.
- The site investigation may have identified contamination but not fully delineated it.

- The locations of the test pits/boreholes and the depths of any samples may bear no relationship to the physical mass of waste soil that needs to be excavated and disposed.

Project formulation activities aligned with the presence of hazardous materials should be considered during the following planning steps:

- Step 1: If hazardous waste is identified within the project area, this poses a significant constraint. Early identification of hazardous waste is critical to minimize wasted time and effort in the plan formulation process.
- Step 2: Investigate hazardous waste within the study area that might impact levee alignment.

If identified during planning or alternative selection, sites with hazardous, toxic, and radioactive waste can be avoided so mitigation will not be required as part of construction. If these sites cannot be avoided, mitigation of hazardous materials may either be the responsibility of others to address prior to levee construction or the rehabilitation requirements should be included as part of the design.

4.5.7 Borrow Areas/Sources of Construction Material

Construction materials may include earthfill, clays, sands, and aggregates, riprap and other erosion protection materials, concrete, structural steel, sheetpiling, and bentonite. The best practice is to identify sources of construction material early in the project formulation process. During this identification process the team should:

- Confirm borrow material can be obtained in a reasonable time to avoid construction delays.
- Ensure the material will meet the requirements for strength, grading, and permeability.
- Allow time to complete environmental and cultural studies.

Borrow sites potentially affecting flood risk—such as excavation adjacent to an existing levee—should be excluded from the project.

Hauling borrow materials will likely be a large cost and an environmental impact driver. In many cases, borrow sources may require processing and mixing before use for the embankment. If material is not commercially available, the levee owner may have to acquire property, or rights to develop a property, to obtain the material. These should be identified early to confirm the source can be used.

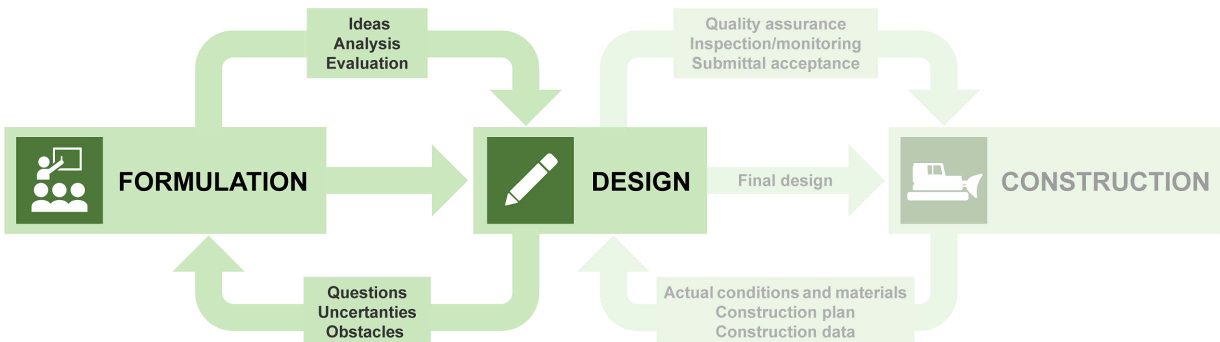
Project formulation activities aligned with the consideration of borrow material should be considered during the following planning steps:

- Step 1: Availability of borrow areas/construction material could be either an opportunity if material is readily available, or a constraint if located far from the project site.
- Step 2: While inventorying current and future conditions, availability of material should be considered if conditions could potentially change. For example, if land use changes from open space (where material is more available) to a developed area (where material is less available).

5 Interaction Amongst Formulation, Design, and Construction

Formulation of a levee project starts with the realization that there is a need for action. From there, an idea or solution is developed. This idea gets expanded and refined throughout the formulation process. As the idea/solution becomes more defined, there is enough information to start the design process. As design nears completion, information is handed to the construction team, such as specifics on final investigations, plans and specifications preparation, site needs, and monitoring plans. This interactive process is shown in Figure 6-16.

Figure 6-16: Interaction Amongst Formulation, Design, and Construction



Formulation and design evolve in parallel, as shown graphically in Figure 6-17, and each informs the other during this evolution. For example, if as the project is formulated, the community rejects a component of the levee, a new idea might be needed and the design changes. Over time, the level of effort for formulation recedes and that of design increases until the final design is reached. Levee formulation activities begin conceptually (conceptual phase); then the feasibility of the conceptual ideas are examined and preliminary design started (feasibility phase); and lastly design is finalized before heading into construction (final phase). Activities within each phase of the levee formulation process are described in Table 6-6.

Figure 6-17: Interaction Between Formulation and Design

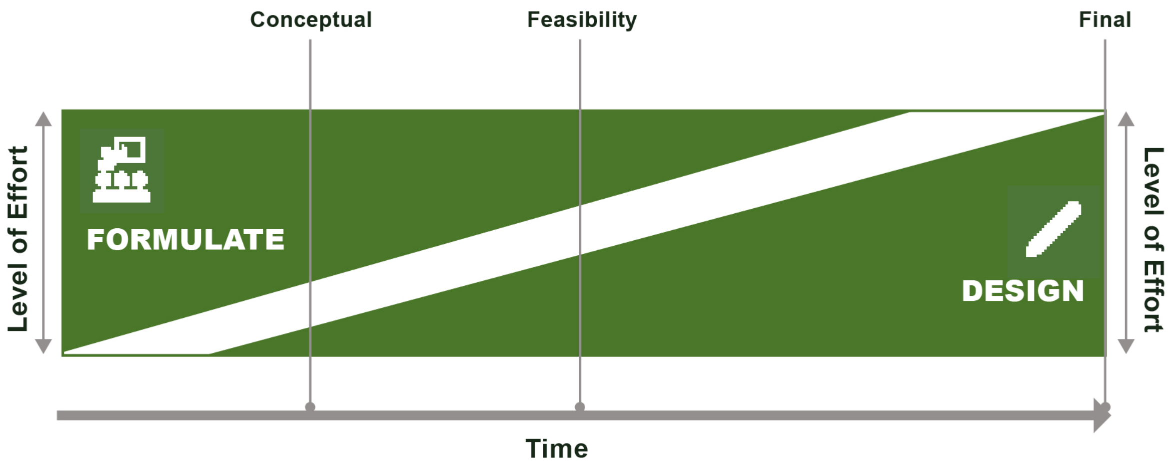


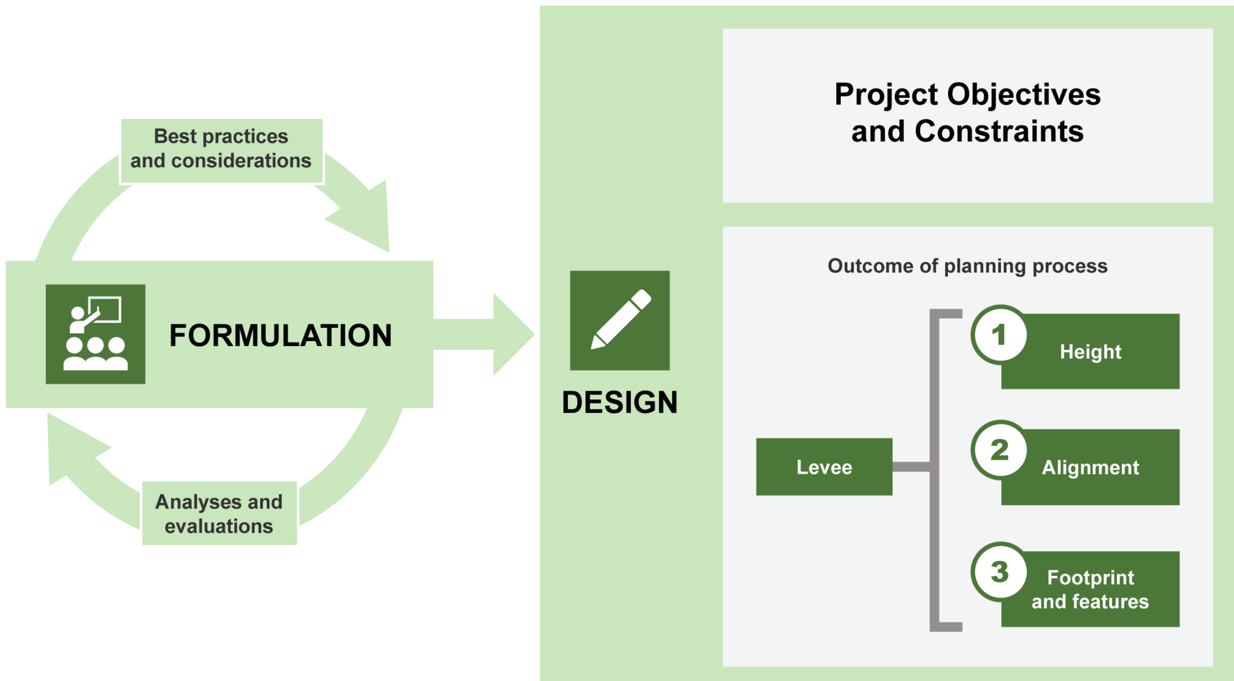
Table 6-6: Activities Within Each Phase of Levee Project

Phase of Project	Activity
Conceptual	Initial assessment based on available information. Some investigation may be required to support the hydraulic characterization of the site. The information is sufficient to allow rudimentary modeling and calculations to be undertaken for a few options, which can be used to assess the viability of proceeding with some form of flood risk management project.
Feasibility	More detailed information gathered, and more extensive modeling and calculations undertaken for a broader array of options. Information is sufficient to allow the options to be worked up to a level of detail that allows them to be costed so that decision makers can determine which option is to be taken forward to design and construction. This may include developing a better understanding of the interaction of the levee, ground, and hydraulics, as well as the issues that will affect the levee performance. Findings allow the scoping of additional data collection (quantity and nature) required for the detailed evaluation. At this stage, the hydraulics are typically well defined but additional field data may be required to support the more sophisticated analytical/numerical models. Where no or very limited quantitative data are available, limited investigations may be required to inform the geotechnical assessment.
Final	The primary objective of this stage is usually the characterization of the ground through a rigorous program of investigation. Some additional hydraulic data may be required but this is usually well defined by this stage. There may be a need to update or refine data, specifically if there is a need for advanced hydraulic modeling. The development of the final project schema and preparation of construction information (plans and specifications at various levels, typically 30%, 60%, 90% and 100% final design) is completed in the final phase prior to going to construction.

Note to table: Adapted from The International Levee Handbook (Eau and Fleuves, 2017).

Engineering analyses and evaluations during levee formulation are needed to identify the levee geometry and features. The goal is to identify these as early as possible and with enough confidence to move into design. To move forward with design, the top of levee profile (levee height), levee alignment, levee footprint, and levee features should be identified, while incorporating the best practices and considerations outlined in section 4. Project objectives and constraints will also be carried through to the design phase as shown in Figure 6-18.

Figure 6-18: Outcome of the Planning Process

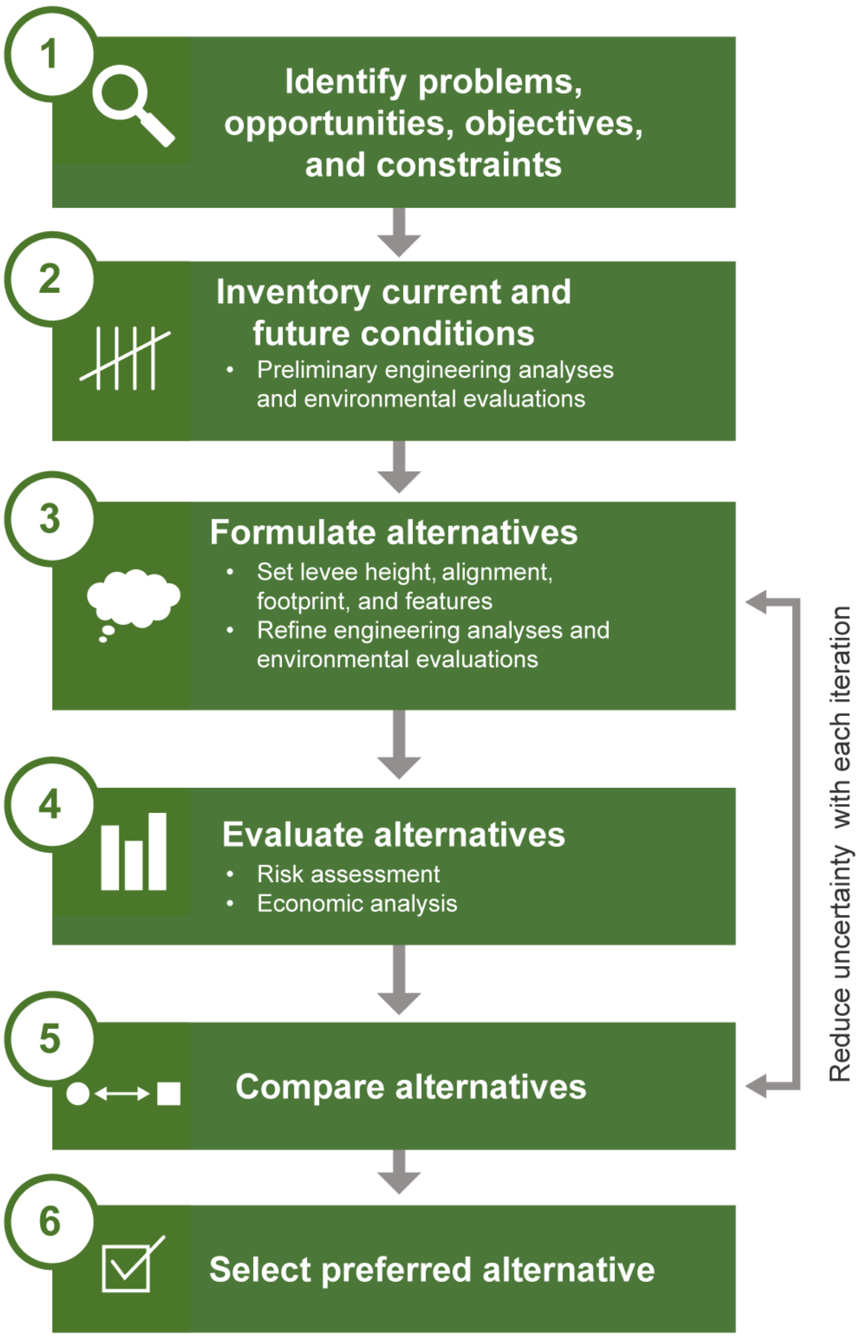


To determine the appropriate levee characteristics for the specified application, supporting analyses, studies, and evaluations are required. Supporting analyses include engineering analyses, risk analyses, economic evaluations, and environmental assessments to set the levee geometry and features. How they are incorporated into each of the planning steps is illustrated in Figure 6-19.

Some preliminary engineering analysis and results from taking inventory of current and forecast future conditions in Step 2 are required in advance to formulating alternative plans in Step 3. This would be done at the conceptual level of planning and design. Once the preliminary levee characteristics have been identified, risk and economic analyses are used to evaluate alterative plans in Step 4. At the conclusion of Step 4, consequences and benefits are better understood for each alternative. At this point, the planning process may become iterative as more data and information is collected.

The iterative process typically is completed within the feasibility phase of planning and design. Within each iteration, the level of uncertainty about each analysis is reduced. This iterative process may continue until the team has decided that the planning objectives have been met and the residual planning risks are acceptable to the community, allowing for the completion of alternative comparison in Step 5 and selecting an alternative in Step 6. Checks for constructability, O&M requirements, and lifecycle costs should be conducted throughout this iterative process. At the conclusion of the feasibility phase, a decision is made to enter into the final phases of planning and design for the selected alternative.

Figure 6-19: Analyses Within the Six-Step Planning Process



5.1 Analysis Considerations

5.1.1 Addressing Uncertainty

Because future conditions are inherently unknown, the best practice is to include a level of uncertainty with current and forecasted future conditions. Levee formulation is a dynamic, iterative process with uncertainties in each step of the process. Assumptions made during evaluations and modeling are used to inform levee formulation, even for current conditions. Uncertainty in these assumptions should also be included. It is important to acknowledge and articulate sources of uncertainty and knowledge limitations.

Further, since levees may exist for a long period of time—some existing levees are close to 100 years old—it is important to consider larger timescales, and hence larger uncertainties when formulating a levee. Key assumptions used in the projections should be explicitly stated. Examples include future population growth, changes in land use, and climate forecast. Where uncertainty may meaningfully affect the investment decision, multiple planning scenarios should be considered, with a clear explanation of the basis and assumptions underlying each.

5.1.2 Scalability

The level of detail and complexity of planning, analyses, and evaluations will depend on the decisions being made, necessary actions to address uncertainty in the results, level of difficulty of the problem, and the cost of addressing the risks. The best practice is to include greater analytic detail in projects with greater uncertainty, complexity, risk, or cost. Whereas for projects with lower uncertainty, complexity, risk, or cost, less analytic rigor may be required. Conversely, in some cases, high risks to life safety may warrant consideration of not waiting for more detailed assessments and proceeding with the study and implementation as quickly as possible.

In addition, the level of detail required to make levee formulation decisions will grow over the course of the study, as the process moves from an array of alternatives to a single recommended alternative.

Factors to consider when determining the appropriate level of analysis:

- Magnitude and significance of specific problems and opportunities the levee project seeks to address, expected impacts, resulting risk exposure, and/or costs.
- Complexity in science, engineering, uncertainties, ecosystems, cultural values, resource management, and best scientific information available.
- Projected service or operational life of the project or facility.
- Stakeholder and community concerns.
- Authority under which the investment decision/recommendation is made and degree of performance or irreversibility of that investment decision.

5.1.3 Planning Area and Levee Reaches

The planning area refers to the specific geographic area where alternative levee plans are formulated and evaluated. The best practice is to specify a planning area that includes the geographic scope necessary for analyzing the nature and extent of problems and opportunities.

Additionally, potential locations of resources and existing projects that would be directly, indirectly, or cumulatively affected by, or that could affect, the alternative plans (often called the affected area) should be considered. In the process of describing problems and opportunities, the planning area may be adjusted to accommodate new understandings of physical, biological, and economic relationships. The planning area is typically larger than the affected area. It is also possible that the geographic boundaries for evaluating hydraulic, economic, and social impacts do not coincide, thus it may be necessary to define multiple (overlapping) planning areas.

For levee evaluations and analyses, sections of the levee may be grouped together as a levee reach. Each reach should be defined by discrete lengths such that each length has similar geotechnical, geometric, past performance, construction and remedial history, and/or hydraulic loading (USACE, 2022). The number of reaches may depend on the stage in project formulation and data availability but should consist of enough reaches to capture proposed project features or changes in cross section.

5.1.4 Available Information

During the formulation process, especially in the early stages, the best practice is to include as much available information as possible (Table 6-7). As the team gets farther along in the process, more refinement and development of project-specific information should be used as analysis results and formulation of alternatives move into design.

Table 6-7: Available Information

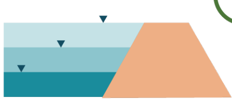
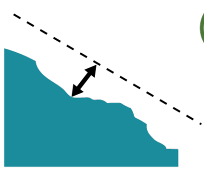
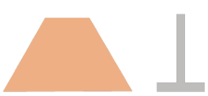
Data	Description
FEMA floodplain mapping	The flood insurance rate maps for an area can help communities view and visualize local flood risk. To access the maps, FEMA has a flood map service center that is searchable by address, place, or longitude/latitude coordinates. In addition to the rate maps, there are supplemental non-regulatory resources available on the FEMA website.
National Levee Database	The NLD is a dynamic database with levee data from federal agencies, states, tribes, territories, and local sources.
Levee Screening Tool	USACE created the Levee Screening Tool to characterize levee risk. Authorized users can enter information related to hazards, conditions, performance, and consequences and apply engineering judgment to describe the performance and potential consequences of the levee system. USACE has applied the Levee Screening Tool to over 1,700 levees in the NLD; these levees are referred to as screened levees.
Water level or tide gage data	National Oceanic and Atmospheric Administration has an online database for tide gage data searchable by location or gage ID. U.S. Geological Survey water data for the nation includes water resource data collected at approximately 1.9 million sites in all 50 states and other areas of the nation.
Geologic and soils data	U.S. Geological Survey geologic maps and Earth Resources Observation and Science data center for imagery, Bureau of Land Management maps and aerial photographs, Natural Resource Conservation Service soils mapping, and state geological surveys.

Data	Description
Previous studies	Research should be conducted to gather available information for the study area that may have been developed previously. This information could include topography, bathymetry data, hydrologic or hydraulic models, utility locations, site investigations, environmental assessments, hazardous materials surveys, or risk analyses. Check with local, state, and federal governments to identify previous studies that may have useful data for the specified project.

5.2 Engineering Analyses

Several types of engineering analyses are required to determine the top of levee profile, levee alignment, levee footprint, and levee features. The types of analyses required, and the results needed to establish these levee characteristics, are shown in Figure 6-20.

Figure 6-20: Engineering Analysis Required for Formulating Levee Characteristics

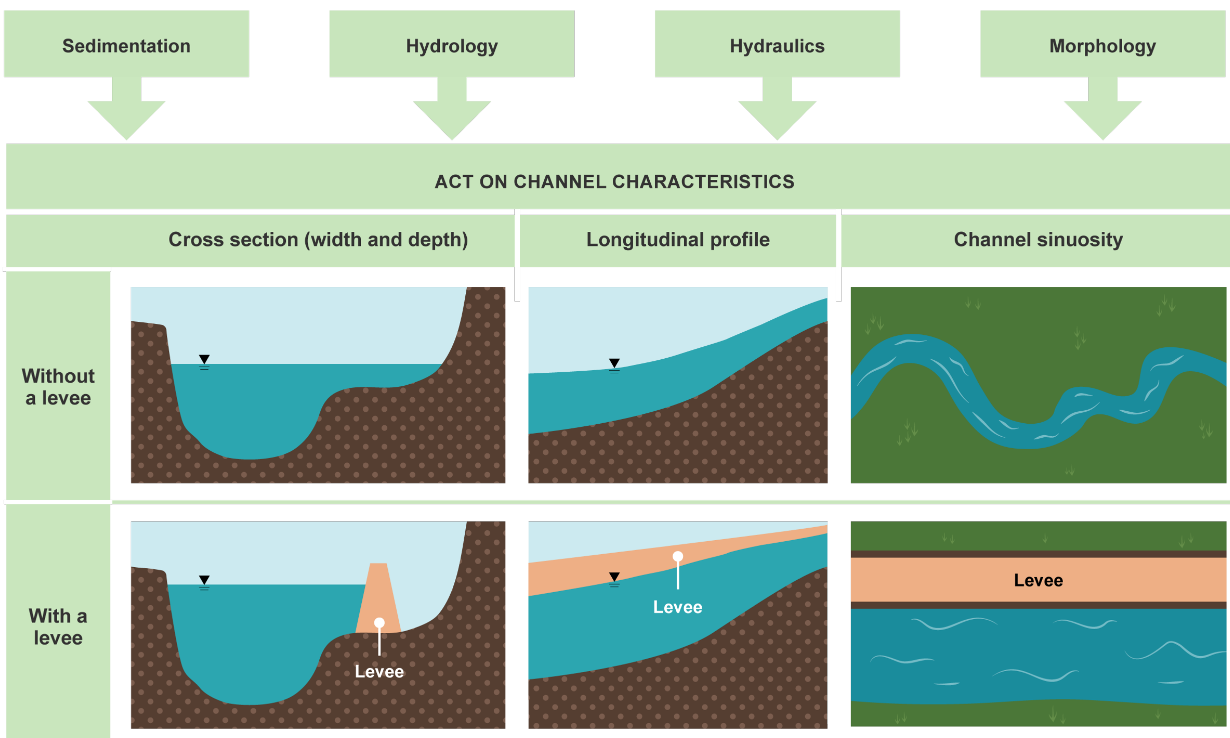
	Levee characteristics	Engineering analyses	Engineering analysis results	Other considerations
	1 Levee height	• River/coastal hydrologic and hydraulic analyses • Wind wave	• Water surface profile • Annual exceedance probability • Wave and storm surge potential	• Superiority
	2 Levee alignment	• River/coastal morphology • Geotechnical	• Geomorphologic process • Subsurface conditions	• Right of way • Interior drainage • Hazardous waste
	3 Footprint and features	• Hydrologic • Geotechnical	• Levee slopes' impact on wave height • Subsurface conditions	• Borrow availability • Right of way

The level of detail in the analyses should be in line with the scale and risk of the project. For levee projects that will reduce flood risk to leveed areas with significant populations and damageable properties, the analysis should be more robust, such as development of detailed modeling, thorough site investigations, and a comprehensive and rigorous evaluation of potential impacts and consequences. For smaller leveed areas with less consequences, a scaled back analysis could be considered, mainly relying on available data and analyses. Regardless of the scale of the project, the flood hazard and potential flood risk reduction provided by the project should be transparent and clearly communicated to the community.

As the plan formulation moves from conceptual to feasibility stages and eventually to final design, the analyses and evaluations required to determine levee characteristics, could become iterative. Once a conceptual plan is conceived and levee characteristics identified, a risk analysis should be performed to understand the reliability of the initial design and residual risks. If the consequences are more significant than a community wants to accept, revision to the conceptual design would be needed. With each iteration, and repeat of risk analyses, the uncertainties about analyses results will be reduced.

Levees are a part of the physical world and must interact within the environment within which they are constructed (Figure 6-21). Hydrology, hydraulics, and sedimentation of riverine and coastal systems are influenced by natural processes. However, the presence of levees will modify and interact with the natural surroundings. In formulating a levee project, it is necessary to understand how natural and human-made systems interact and affect each other. For example, wetland restoration can lead to changes in wave heights through the frictional effects of vegetation blades, stems, and branches on water flow, and reduce the loading on coastal levees, which, in turn, can influence damages and maintenance costs. Setting back levees from the watercourse provides more storage for larger storms and helps reconnect the floodplain and restore ecosystems. At the same time, a wider floodplain allows the river to follow a more natural meander slowing water flow and erosion, and thus reducing the risk of levee scour. Thus, there is a need for engineering analyses with the levee project in place to understand how it could potentially alter existing conditions.

Figure 6-21: Interaction Between Levees and Physical World



Note to figure: Adapted from The International Levee Handbook (Eau and Fleuves, 2017).

5.3 Risk Assessment

During formulation of a levee project, flood risks need to be estimated and understood. The type of levee project will guide the risk assessment and risk estimates required, as illustrated in Table 6-8. Guidance on estimating risks is provided in **Chapter 4**. In addition, **Chapter 5** provides guidance on investment strategies related to balancing flood and levee risks that should be considered in levee project formulation, including the type of levee project. For example, if a rehabilitation project is needed to reduce levee risks and the extent of the work required is significant, there may be an opportunity to increase the risk reduction benefits provided by the levee.

Table 6-8: Levee Project Type and Risk Estimates

Levee Project Type	Risk Estimates
New	• Flood risk without the levee. • Optimizing level of risk reduction provided by levee. • Non-breach risk with levee in place. • Levee risk (prior to and with overtopping). • Flood risk from other sources with levee in place.
Rehabilitate	• Existing/intended risk reduction benefits. • Non-breach risk. • Levee risk (before and after rehabilitation). • Optimizing level of risk reduction provided by the levee. • Impacts of rehabilitation on flood risk from other sources.
Modify	• Existing risk reduction benefits of the levee. • Target risk reduction benefits provided by levee. • Non-breach risk (existing and modified). • Levee risk (existing and modified). • Impacts of modification on flood risk from other sources.
Remove	• Existing risk reduction benefits of the levee. • Non-breach risk (existing). • Levee risk. • Flood risk without the levee.

5.4 Economic Analyses

Economic analyses are often used in the levee plan formulation process to evaluate the effectiveness and efficiency of potential alternative plans. Various types of economic analyses can be performed to evaluate alternatives.

5.4.1 Benefit-Cost Analysis and Cost-Effectiveness Analysis

Benefit-cost analysis is commonly used to identify and measure (usually in monetary terms) the different benefits and costs of proposed alternatives and then compare with each other to determine if the benefits of the alternative exceed its costs. It is a systematic process for identifying, quantifying, and comparing expected benefits and costs of an investment. All benefits and costs that arise during the life of the project are included in the analysis. For alternative comparison purposes, benefits and costs over the project life are brought to a present-day value using a discount rate. Benefit-cost analysis is the primary method used to identify whether an alternative is economically justified. An alternative is justified when:

- Estimated total benefits exceed total estimated economic costs.
- Each separable purpose (for example flood damage reduction or ecosystem restoration) provides benefits at least equal to its costs.
- The scale of development provides maximum net benefits (in other words, there are no smaller or larger alternatives which provide greater net benefits).
- There are no means of accomplishing the same purpose which are more economical.

Various types of benefits and co-benefits in a levee project can be included in a benefit-cost analysis, which could include but are not limited to:

- Flood damage reduction.
- Recreation.
- Ecosystem restoration.

Federal, state, and local agencies have specific methods, assumptions, and benefit categories that may be included in benefit-cost analyses. The most relevant guidance—and that which is most appropriate to the project—should be investigated.

Cost-effectiveness analysis focuses upon comparing the whole life costs of alternatives, which achieve or exceed an objective, that can be expressed in specific, non-monetary terms (i.e., acre-feet, milligrams per liter, habitat units). For example, if the objective of the project is to reduce the floodplain depth to less than 1 foot, then a cost-effectiveness analysis would compare the costs of alternative plans that meet or exceed that objective. The plan that delivers the specified objective at the least cost would be the most cost-effective alternative. Cost-effectiveness analysis is particularly important when the objective cannot be monetized and therefore cannot be included in a traditional benefit-cost analysis. Ecosystem restoration benefits are an example of this. Although there are techniques to place monetary values on the outputs of ecosystem restoration projects, traditionally these types of projects are evaluated by computing the cost-per-restored-habitat-acre or some other physical measure (such as habitat units), and comparing these costs, as well as the incremental changes in costs and outputs among proposed alternatives (California DWR, 2008).

5.4.2 Incremental Analysis

Incremental analysis is a process used in plan formulation to help identify alternatives that deserve further consideration in an efficient manner in USACE's ER 1105-2-100 (USACE, 2000b). The analysis consists of examining increments of alternative plans to determine their incremental costs and incremental benefits. Increments of plans continue to be added and evaluated as long as the incremental benefits exceed the incremental costs. For example, a project might start with a levee of low height, then add height in steps or increments (say 1 foot). For each increment of height, the added (incremental) costs and added (incremental) benefits are estimated. As long as the incremental benefits exceed the incremental costs, it makes sense to add the foot of height because the extra foot adds more to benefits than to costs. When incremental costs exceed incremental benefits, no further increments of height are added (USACE, 2000b).

5.4.3 Trade-off Analysis

Some project benefits are not easily expressed in monetary terms, such as ecosystem restoration or recreational features. Trade-off analyses include defining monetary and non-monetary effects of a project as gains and losses.

5.4.4 Distribution Effects

Traditional benefit-cost analyses produce information monetizing the benefits to justify project costs; however, it does not distinguish which groups within a society benefit more or less. Evaluation of distributional effects might be answered by asking: does the project benefit some groups more than others? Are benefits being equally distributed amongst the community? Economic techniques can be used to weight benefits and/or costs to better reflect the community impacted.

5.5 Environmental Evaluations

Environmental impact studies should be conducted in coordination with federal, state, tribal, and local environmental agencies as part of any planning process for a new levee. Levee alignment and footprint should minimize the impact to the environment. This is especially true where there is critical habitat along the levee. In these regions, it is generally desired that allowances be made for waterside vegetation along the bank as it provides critical habitat and shading (beneficial for water temperatures) for aquatic species. This can sometimes be accomplished by setting the levee back from the watercourse. In some cases, a levee setback is not an option, and consideration of features that allow for the coexistence of habitat or vegetation along or near the levee should be considered.

6 Establishing Levee Characteristics

6.1 Establishing Design Hydraulic Conditions

The hydraulic conditions for project formulation and design should be evaluated based on hydraulic modeling that provides water levels (or water levels and wave conditions in coastal situations) along the levee alignment. Hydraulic models are used to estimate a design water level and ultimately set a design top of levee grade (section 6.2).

Both hydrologic and hydraulic models should be calibrated using observed data wherever this is available. Data may include aspects such as historical high-water events, areas flooded, and/or wave conditions. Older data may require conversion to current horizontal and vertical datums. Where no significant changes have occurred in the watershed and existing levee alignments have not changed, the amount of modeling may be reduced if the period of record is sufficient to derive a reasonable estimate of long-term water levels. Known climate change trends should be used to adjust predictions and historic data.

Following this evaluation, design water level and wave loadings on the levee features should be established together with a range of other conditions above and below these design conditions against which the performance of the levee should be checked. Areas where insufficient topography is available to assess the design loads should be identified for further survey or bathymetry. The outcome of hydrologic and hydraulic evaluations are design water levels, flows and wave conditions used to set levee geometry (Table 6-9).

Table 6-9: Hydrologic and Hydraulic Activities Within Each Phase of a Levee Project

Phase of Project		Typical Information	Use of Information
Conceptual	Office based data collection	• Bathymetry • Topography, light detection, and ranging • Aerial photographs • Rudimentary models • Approximate estimates of stage-discharge relationships • Statistics for available gage data • Information from existing studies	• Provide a general understanding of the river, coastal, or estuarine system. The level of understanding will vary with the extent of information available. • Provide information to inform scoping of subsequent phases of investigation. • Provide information to support preliminary project/design decisions.
	Field based data collection	• Observation of stream channel, sediments, vegetation, floodplain, existing infrastructure, and flood control features • Identify potential impact areas • Morphologic assessment of river or coastal system • Water levels • Waves and currents • Topography	
Feasibility		• Additional bathymetric and topographic surveys • Develop detailed hydrologic and hydraulic models for river, coastal, or estuarine systems • Morphological studies • Perform risk-based analysis	• Support development of higher resolution models. • Assess system performance. • Evaluate alternative solutions. • Set top of levee elevation. • Determine designed overtopping location requirements.
Final		• Develop O&M manual • Design of designed overtopping sections • Detail calculations/modeling for erosion protection	• Provide owner information and instructions to operate and maintain project. • Provide sufficient information to allow the detailed design to be developed.

Note to table: Adapted from The International Levee Handbook (Eau and Fleuves, 2017).

6.1.1 Hydrologic Evaluations for Riverine Levees

As described in **Chapter 4**, hydrology relates to the estimation of precipitation intensity and duration, the resulting quantities of surface water runoff generated from a specific area or watershed and the resulting stream flow in rivers. Watershed hydrology thus governs water surface elevations in streams and rivers and knowing the magnitude and probability of large events is critical in levee formulation and design.

6.1.2 Hydraulic Evaluations for Riverine Levees

Hydraulic evaluations estimate the range of flow and water level characteristics that may occur in rivers, from those in rare, large floods to normal, everyday flows. Such evaluations should be repeated throughout the levee lifecycle, since water levels and flows in rivers continually change due to precipitation, watershed runoff, and changes in channel morphology. Details on recommended approaches to hydraulic evaluations and hydraulic modeling are provided in **Chapter 4**.

The results of these evaluations inform levee geometry (sections 6.2, 6.3, and 6.4), which includes levee height, footprint, features, tie-ins, alignment, and managed overtopping.

A probabilistic hydrologic and hydraulic risk and uncertainty analysis, including climate change considerations, may be performed to assess the confidence in forecasted water levels. Based on the likelihood of water levels exceeding the design top of levee grade, this analysis may suggest additional levee height. Allowance should also be made for the following:

- Increased water levels near bridges and other structures.
- Wave runup (where significant wave action is possible) making use of the recommendations for coastal levee situations in **Chapter 4**.

6.1.3 Hydraulic Evaluations for Coastal Levees

For coastal levees, the design top of levee grade will be set on the basis of hydraulic studies which consider the effect of wind, water level, and climate, together with wind and wave setup, wave runup and overtopping calculations (**Chapter 4**). The outputs of the studies will be estimates of water level and wave conditions for a range of annual exceedance probabilities, or return periods. These should be provided at a series of locations along the levee system identified with levee design cross-sections (transects), and delivering these may require local wave transformation calculations.

At these locations, runup, and overtopping calculations may then be undertaken, often using empirical models to help to determine levee geometry. In addition, the wave conditions at the levee will determine any armoring required. In complex situations, physical models may be required to assess wave overtopping and armoring.

SEA LEVEL CHANGE CONSIDERATIONS

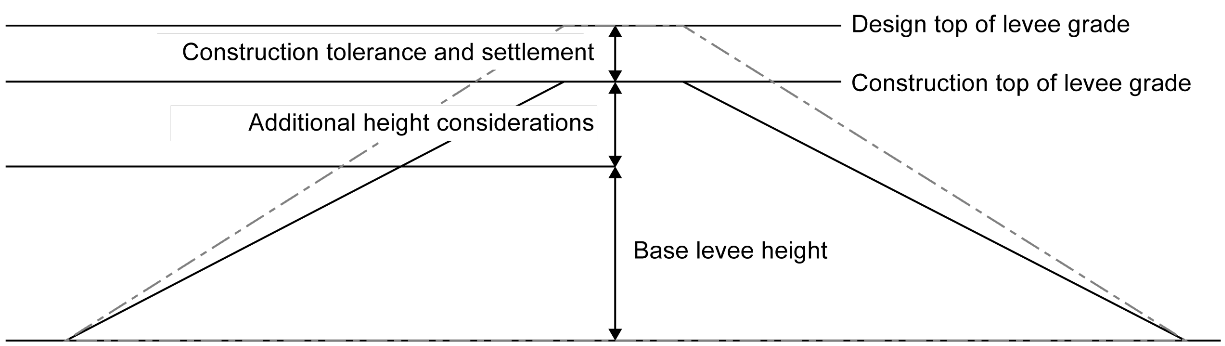
For coastal levees, a range of future relative sea level change scenarios will need to be incorporated in the two-dimensional coastal hydraulic model, providing a comprehensive understanding of how changing long-term water levels can impact storm water levels, as typically this relationship is not linear. If that is not possible, a relative sea level change increase can be applied to water levels from current conditions in planning stages, although understanding the localized effects and impacts on wave conditions will lack accuracy without running the complete storm scenarios in the two-dimensional hydraulic model.

6.2 Setting the Top of Levee Grade

The top of levee grade represents the top of the barrier at a particular location along a levee system. The objective for determining the top of levee grade is to determine a minimum top of levee grade that will accomplish the intended objectives of the levee. The minimum top of levee grade for a levee embankment is denoted as the design top of levee grade shown in Figure 6-22. The same approach can be used for other levee features such as floodwalls, closure structures, etc. There are three typical components for determining the design top of levee grade:

1. Base levee height.
2. Additional height considerations.
3. Construction tolerance and settlement.

Figure 6-22: Determining Top of Levee Grade



Paving, including asphalt, concrete, gravel, or aggregate-type surfacing should be above the design top of levee grade and considered with setting the construction top of levee grade.

6.2.1 Base Levee Height

The base levee height is the height of the levee that represents the highest water surface profile for the range of flood events the levee is intended to exclude from the leveed area. Hydrologic and hydraulic evaluations are used to determine water surface profiles and are typically performed using deterministic methods (i.e., does not explicitly account for uncertainty) with expected hydrologic and hydraulic evaluation values over the analysis period. Adjusting the levee height to account for uncertainty in hydrologic and hydraulic evaluations is discussed more in section 6.2.2 (e.g., hydraulic assurance). The hydrologic and hydraulic evaluations to determine water surface profiles for the base levee height should account for the following expected conditions over the analysis period:

- Discharge rates (i.e., flow) based on expected future rainfall and runoff.
- Localized infrastructure influence on water levels (e.g., bridges).
- Channel/river curvature effects (e.g., super elevation water surface profile).
- Channel/river conveyance roughness and cross-section geometry.

- Effects of waves.

When waves can occur during a flood, the base levee height should be increased above the still water surface profile to include the effect of waves on water levels for the range of water surface elevations the levee is intended to exclude. Waves can occur during coastal flooding or riverine flooding with significant wind and fetch distances. Wave runup occurs when individual waves break on the waterside levee slope and the broken wave bores advance up the slope. Refer to sections **Chapter 4** on how to determine effects of waves.

6.2.2 Additional Height Considerations

Determining the design top of levee grade also requires incorporating other considerations in addition to the base levee height (Figure 6-22). There are many factors that influence these other considerations, but the primary factors for additional height considerations include:

- Hydraulic assurance
- Subsidence
- O&M access
- Superiority
- Uncertainty

Currently in practice, a combination of deterministic methods (i.e., does not explicitly consider uncertainties) and probabilistic methods (i.e., explicitly consider uncertainties) are used to determine the additional levee height related to these factors. The best practice is to use probabilistic methods, which consider the likelihood or probability of water surface profiles occurring to determine additional levee height. Using probabilistic approaches to systematically account for uncertainties is particularly important when evaluating overtopping risk where a levee breach could lead to significant consequences.

SUBSIDENCE

Approximate point of maximum subsidence in the San Joaquin Valley, California. The land surface subsided roughly 9 meters from 1925 to 1977 due to aquifer-system groundwater withdrawals. Signs on the telephone pole indicate the former elevations of the land surface in 1925 and 1955. (Credit: Richard Ireland; U.S. Geological Survey.)

Hydraulic assurance is the probability that a water surface profile will not be exceeded during a flood with a particular frequency of occurrence considering the full range of uncertainties in the hydrologic and hydraulic evaluations. Determining the levee height needed for hydraulic assurance is best performed using probabilistic methods. ER 1105-2-101 (USACE, 2019) is a good source of information on how to determine hydraulic assurance. A 90% hydraulic assurance is a common target used to ensure a levee can exclude any floods from the leveed area with a reasonable level of confidence. A 90% hydraulic assurance means that there is a 90% probability that the top of levee grade will not be exceeded (i.e., overtopped) for these floods. Achieving a 90% hydraulic assurance can require 2 to 3 feet of additional levee height above the base levee height in riverine situations.

Subsidence is a gradual settling or sudden sinking of the Earth's surface due to removal or displacement of subsurface earth materials. Subsidence can be caused by human-made activities (e.g., aquifer-system compaction associated with groundwater withdrawals) and/or natural processes (e.g., natural compaction or collapse such as with sinkholes or thawing permafrost). Subsidence is an important consideration when determining the design top of levee grade especially for levees intended to exclude coastal floods. Regional datums provide practices for estimating subsidence rates. When selecting additional levee height, the project team should consider:

- The amount of the levee height adjustment needed to account for subsidence impacts on both the design levee grade and flood water surface profiles.
- Adjusting the levee height to account for subsidence over the analysis period for the project.
- That the goal of the adjustment is to ensure the levee excludes the floods it is intended to rather than maintain a design levee grade.
- For coastal levees, subsidence will only impact the design levee grade—not the water surface profile. Levee height subsidence adjustments will be to maintain the design levee grade.
- For riverine levees, subsidence may impact the elevation of both the design levee grade and water surface profiles.

> **FREEBOARD**
>
> Freeboard is an outdated method of levee design that adds a factor of safety to levee height to account for uncertainties, usually expressed in feet above a specified flood level. Freeboard has been used to compensate for unknown factors (i.e., hydrology and hydraulic uncertainties) that could result in greater flood heights than calculated. Freeboard is a deterministic method used to account for these uncertainties.
>
> For levees, it is not considered a best practice to solely rely on deterministic methods such as freeboard to determine the final top of levee grade. Deterministic methods do not account for the full range of uncertainties and can result in additional levee heights that are too low or too high.

The top of levee often provides important O&M access for the levee. Roads built on top of the levee are typically made up of materials that are pervious (e.g., gravel) and are not typically considered to be an effective barrier to exclude flood waters. Paving, including asphalt, concrete, gravel, or aggregate-type surfacing should not be considered as part of the levee excluding flood water from the leveed area. Thus, the levee height should be increased to account for the O&M access (e.g., the thickness of the road).

Superiority is an important consideration when determining the final top of levee grade. As discussed in section 4.1.2, superiority helps to manage levee risk and flood risk by managing overtopping within a levee system and flooding within a watershed. Determining the levee height needed for superiority requires careful consideration of flood risk transfer within a watershed, as well as tradeoff between levee overtopping performance, levee overtopping consequences, and levee project construction costs. A risk assessment may be used to establish adjustments to the levee height (higher or lower) at different areas of the levee alignment to preferentially select where the levee will overtop in areas of lower consequence.

Accordingly, levee height adjustments may be greater in some areas of the alignment than others. The amount of added levee height might also depend on the ability of the levee to resist breaching from an overtopping event, termed overtopping resilience. Different methods to increase overtopping resilience may be employed during design. These will include design of erosion-resistant elements on the levee crest and landside slope or the use of designed overtopping sections, typically in conjunction with superiority.

At the coast, further levee height adjustments may be necessary in order to limit the amount of wave run-up and overtopping to acceptable quantities. The extent of height increase can be moderated by adding additional roughness elements to the water side of the levee.

6.2.3 Settlement and Construction Tolerance

The difference between the construction top of levee grade and the design top of levee grade is based on the amount of settlement that is expected to occur after construction and the tolerance (i.e., variation of elevation) allowed during construction. Thus, settlement and construction tolerance are important considerations for determining the top of levee grade to be shown on construction plans to ensure the desired design top of levee grade is achieved.

Settlement can occur due to consolidation of soils both within the levee embankment and its foundation when constructing a new levee or modifying and/or raising an existing levee. It is important to account for this settlement to ensure the constructed top of levee does not settle below the final top of levee grade. The construction top of levee grade shown in Figure 6-22 includes the expected settlement. Refer to **Chapter 7** for approaches to determine settlement and methods for settlement control.

Levee construction work typically has tolerances to allow for inherent variances in construction materials and workmanship skills. The inclusion of tolerances are an integral part of quality designs and determining the construction top of levee grade. Tolerance in construction is a permissible deviation from a dimension, construction limit, or physical characteristic of a material. Permissible construction tolerances should be carefully considered and specified in the construction documents. Construction tolerances above the top of levee grade (plus tolerances) are typically in the range of 0.10 foot, but a higher amount of plus tolerance may be used with careful consideration of the impacts. Construction tolerances below the construction top of levee grade (minus tolerances) should not be allowed.

The top of levee grade should also account for post-construction settlement in establishing construction top of levee grade. As discussed in section 6.1, the levee should be over-built, to account for the expected settlement.

6.3 Levee Alignment

When setting a levee alignment, several factors should be considered, which could include but not be limited to:

- Alignment of existing levees
- Underlying soil conditions
- Geomorphological processes
- Potential hydraulic impacts
- Environmental benefits
- Habitat

- Accommodation of interior drainage
- Proximity of existing high ground
- Existing and future land use
- Location and use of designed overtopping locations and temporary flood storage areas
- Location of existing and/or planned utilities
- Existing vegetation

As discussed in section 4.5.2, right-of-way constraints may limit alternatives for setting the levee alignment. Right of way obtained for the levee should include adequate room for maintenance, inspection, performing flood inspections, and floodfighting.

Geotechnical analyses will be required to understand subsurface ground conditions and how they may impact levee performance with the proposed alignment. In initial stages of plan formulation, all existing geotechnical data should be collected and used to evaluate and compare the conceptual levee alignments for the range of alternatives. As the project moves into the feasibility stage, limited on-site field investigation may be required to collect site-specific information for one or more preferred alternatives. Geotechnical exploration at this stage might include standard penetration testing or cone penetration testing to identify soils and provide a rough estimate of soil strength. During final design, a rigorous program of site investigation will be required to characterize the levee foundation soils. Additional information on subsurface investigations can be found in section 6.3.4 and Engineering Manual (EM) 1110-2-1913 (USACE, 2000a).

When considering new or modified levee projects, opportunities for levee setback should be included. Setting back a levee from the main channel can mitigate impacts to channel flow capacity, potentially preventing or minimizing the transference of flood risks to areas outside of the leveed area. Setting back levees also offers the potential for environmental benefits by preserving existing floodplains or reconnecting the floodplain to areas that have been cut off (**Chapter 11**).

The presence of utilities may dictate the alignment of a levee. Before proposing a levee alignment, be sure to check with the local utility department to locate all existing and planned utilities. In some cases, it will not be possible to avoid all existing utilities and they will have to be relocated. Utility relocation can add significant costs to a levee project.

The alignment of the levee can also be designed to create areas for the storage of interior drainage during times when gravity pipes through the levee are closed. The amount of storage required will depend upon the level of risk reduction desired from interior drainage flooding and whether a pump station will be constructed as part of the levee system.

6.3.1 Temporary Flood Protection

Ideally, levee work should not be scheduled during known flood prone seasons. Furthermore, there may be levee reaches where temporary flood protection is not practical, in which case specifications should limit construction to outside of the flood season. However, if work has to be scheduled during flood prone seasons, flooding should be minimized and limited to the extent possible by temporary flood protection measures.

The alignment of the temporary flood protection should be determined during the formulation process and be arranged such that when operating, the resulting river levels are no higher than they would have been prior to commencement of construction. The selected height and geometry of the temporary flood protection should take into account the likely severe water level/wave events associated with the period of construction. The selected water levels may be lower than those used for the design of the permanent levee system. In this case, a plan for any necessary emergency raising should also be developed. Because, for any given water level, encounter probabilities will be lower for the relatively short construction period. Encounter probability is the likelihood of the design event being exceeded within the design lifetime.

DESIGN EVENT SEVERITY FOR TEMPORARY FLOOD PROTECTION

It is suggested that the encounter probability of the selected design event for the temporary protection should be of the same order as that for the permanent levee system. Thus, if the permanent levee is designed for a 500-year return period event with a design life of 50 years, it will be appropriate to design the temporary flood protection for a construction period of 3 years for a 30-year event. Encounter probabilities or return periods of design events can be calculated using the simple equations:

Encounter Probability (%) = (1-(1-1/Return Period(year))^Period(year))*100.

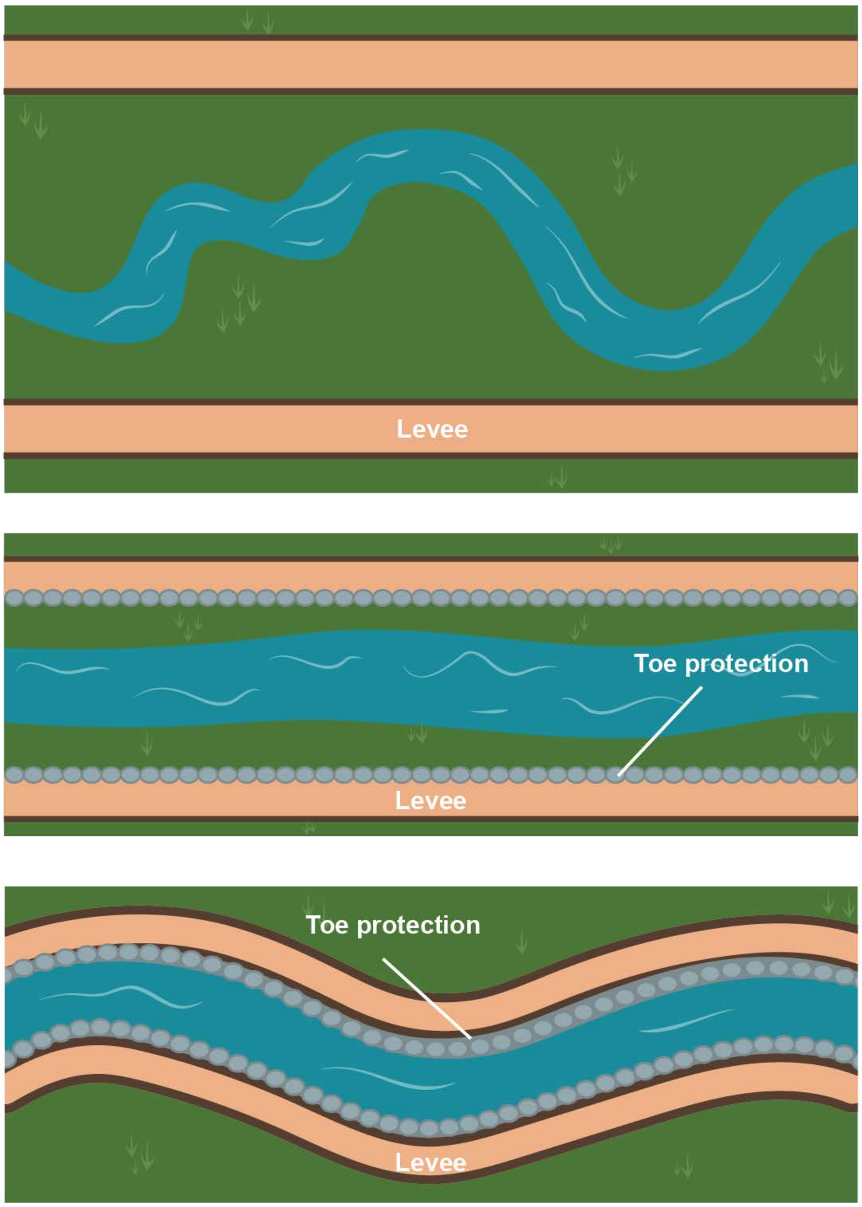
Return Period(year) = 1/(1-(1-Encounter Probability(%)/100))^(1/Period(year)).

The temporary flood protection should also be designed such that levee risk (**Chapter 4**) is not increased during construction.

6.3.2 River Morphology

A river's morphology is the relationship of the stream channel and floodplain to the geology and physiology of the region. Factors that will affect a river's response to its natural environment include sources and supply of sediments, vegetation, previous catastrophic events, earth movements, changes in land use and development, and past human intervention, such as construction of levees, hydraulic structures, or dredging. Methods and data needed to investigate a system's geomorphology include researching aerial photographs, maps, surveys, hydrologic records, soil reports, and consultation with local residents. Understanding historic channel behaviors will inform future morphology. A river's course will likely change over time and will impact levee alignment. Its riverine (fluvial) geomorphologic process—which includes erosion and deposition of sediments—could also influence the need for increasing levee stability and preventative erosion measures. Given a river's geomorphology and anticipated natural progression over the levee lifecycle, variations on levee alignments should be considered as shown in Figure 6-23.

Figure 6-23: Variations in Levee Alignments



a. Wide setback

b. Moderate setback with continuous bank and toe protection

c. Realigned and confined sinuous channel

After project alternatives have been developed, evaluation of potential impacts the project might have on the system should be investigated. Once a system's natural processes have been altered, it is most likely the stream or channel will respond by altering the channel cross section, slope, or planform. A channel's planform describes the channel type as being straight, meandering, or braided. Initial response may only occur mainly within the project reach, but long-term response may affect upstream and downstream reaches.

6.3.2.1 Sedimentation

There is a delicate balance between a basin's runoff, channel velocity and depth, concentration and size of sediment particles moving with flow, the width, depth, slope, hydraulic roughness, planform, and lateral movement of the stream channel. This is a dynamic balance that changes frequently within nature where changes can be exacerbated with human intervention such as a levee project. Sedimentation is not equally likely along the entire project reach. In general, potential for greatest sediment problems is likely at:

- Increased channel width.
- Bridge crossings.
- Abrupt breaks to steeper channel bottom slope.
- Reaches where the channel bottom slope becomes flatter.
- Changes in channel alignment.
- Tributaries entering or water diversions.

Sedimentation studies should be conducted to identify areas of excessive erosion and deposition. Data sources include U.S. Geological Survey, National Weather Service, Natural Resources Conservation Service, Agricultural Stabilization and Conservation Service, and state and local agencies. Levee projects create both sinks and sources for sediment with deposition of sands and gravels or the erosion of sands and silts. Consideration of a movable bed and the sediment exchange rate between the water column and bed surface is complex. Methodologies in sediment transport computations and estimates are provided in EM 1110-2-1416 (USACE, 1993) and EM 1110-2-1418 (USACE, 1994a). Computer programs such as those provided by USACE Hydrologic Engineering Centers include tools that provide one- and two-dimensional sediment transport, as well as mud and debris flow capabilities.

6.3.2.2 Erosion

The potential for erosion must be evaluated and addressed in plan formulation and design, as it is one of the principal causes of levee damage and can lead to both overtopping and prior-to-overtopping failures, as described in EM 1110-2-1913 (USACE, 2000a). Loadings due to stream velocity and/or wind-wave action produce hydraulic shear stresses that can act on an embankment slope and potentially compromise the levee cross section. The degree of erosion will depend on the hydraulic loading, duration of loading, topography and bathymetry, soil characteristics, vegetation, and armoring (if any). Erosion is increased by a number of factors that might include:

- Compromised levee prism geometry.
- Geomorphologic trends as indicated by channel migration and historical damage.
- Streamflow velocity, depth, duration, and shear.
- Wind-wave shear stress.
- Levees, stream banks, or berms constructed of erodible materials.
- Detrimental hydraulic anomalies, such as encroachments.
- Absence of beneficial vegetation or other slope protection (described in Appendix D of the Central Valley Flood Protection Plan: Conservation Strategy) (California DWR, 2017).

Velocity and shear stress computations for assessment of erosion potential can be found in EM 1110-2-1913 (USACE, 2000a) and EM 1110-2-1601(USACE, 1994b). EM 1110-2-1416 (USACE, 1993) and EM 1110-2-1418 (USACE, 1994a) provide guidance on hydraulic considerations for scour and deposition and evaluation of channel and project stability, respectively.

6.3.3 Coastal Morphology

Coastal morphology is the study of the morphological development and evolution of the coast as it is modified by the influence of winds, waves, currents, and sea level changes. The alignment of coastal levees should ideally be set back in such a way as to limit their impact on coastal change. Setting levees back from the immediate coast can also allow space for wave energy to be absorbed by intermediate beach systems, salt marsh and mangrove areas, with the result that levee heights can be reduced.

Levees built too close to the coast may lead to coastal erosion in two particular locations:

- In areas in front of the levee in locations where the mean sea level is rising. Levees in such locations can cause the active coast (including any mangrove or marsh areas) to be subject to ‘coastal squeeze’ (Figure 6-24) and limit the natural sedimentation that would compensate for rising sea levels.
- In areas downdrift from the leveed area due to wave-driven transport of sediment along the shore. The levee traps sediment updrift and thus causes shore erosion on the downdrift side (Figure 6-25). Continued shoreline erosion may undermine the levee and cause damage to land or property along the shore. Coastal erosion may also arise in the future as the distance between the levee and the shoreline reduces due to sea level rise.

EM 1110-2-1100 (USACE, 2002) provides details of approaches to assessment of coastal sedimentation and erosion.

Figure 6-24: Impact of Levees on Coastal Sediment Movement

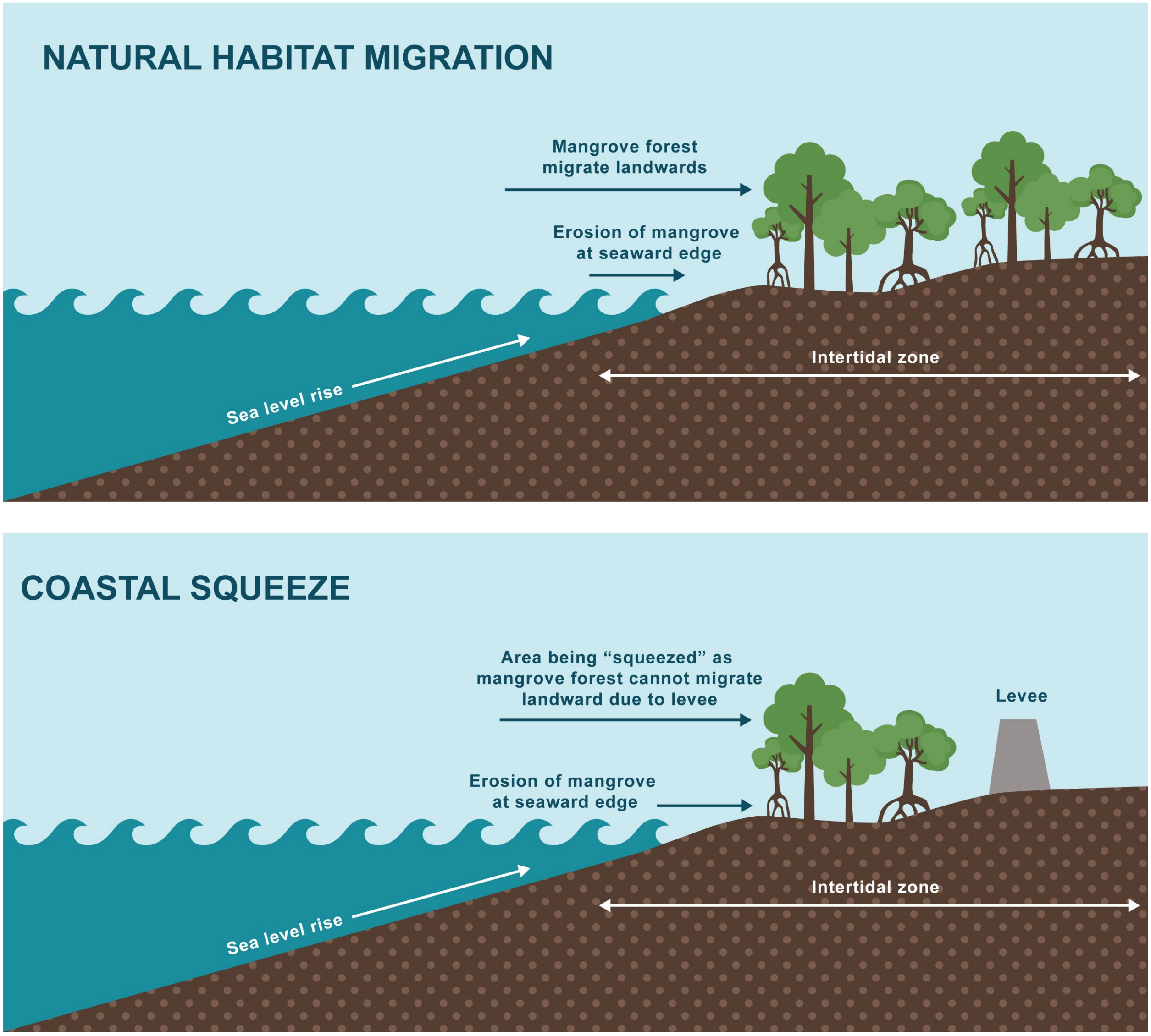
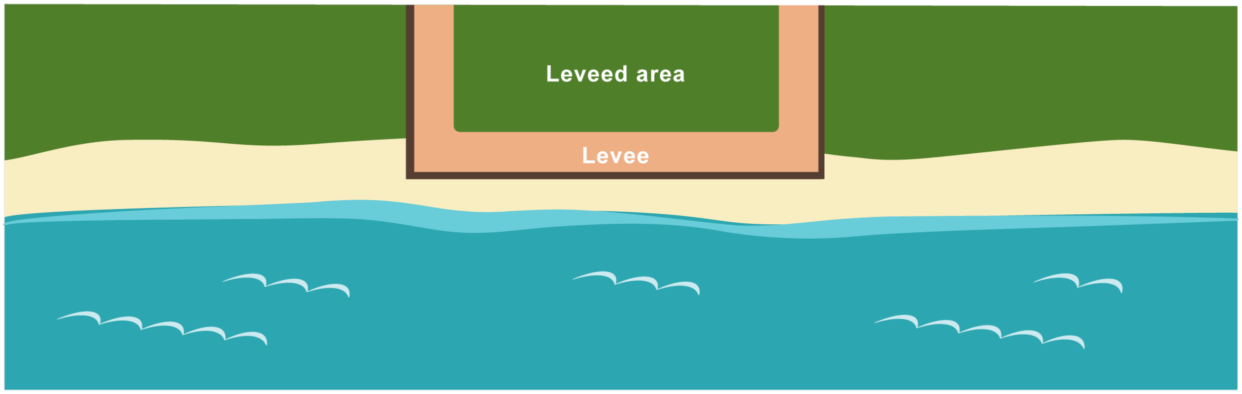
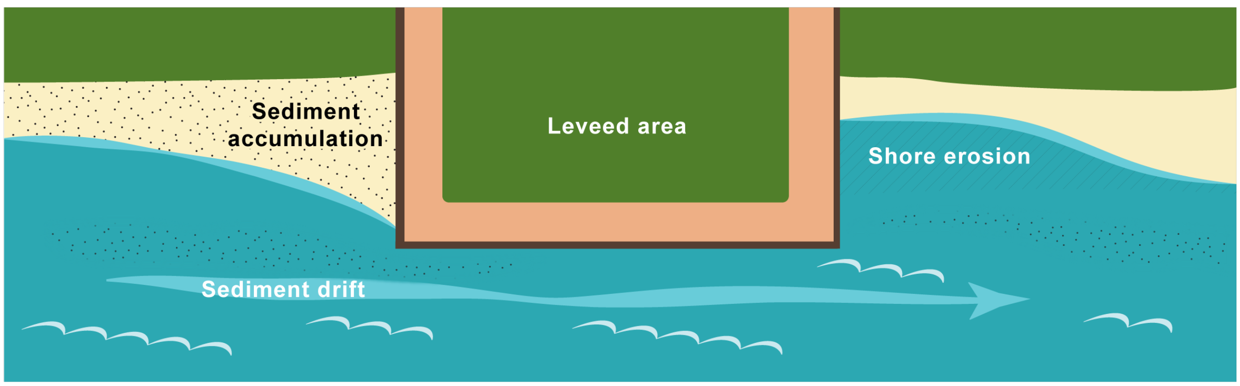


Figure 6-25: Example of Wave-Driven Sediment Transport



Alignment 1



Alignment 2

6.3.4 Site Investigations

Site investigation is discussed in detail in the site characterization part of **Chapter 7**. Results are used to inform the planning, design, and construction of the levee. Investigation can be costly and time-consuming and should therefore be carefully planned to optimize the information obtained. The purposes of the geologic and site investigations for setting the levee alignment and top of levee elevation should include:

- Characterizing existing levee features, including embankments and berms.
- Obtaining geological and geotechnical data to develop design analyses parameters.
- Characterizing foundation conditions to help evaluate alternate levee alignments and to assess settlement (see below) when determining levee height.
- Developing reach and sub-reach boundaries.

The planning of site investigation should be informed by prior risk assessment. Areas of higher risk will likely need a higher intensity of geotechnical exploration, characterization, and analyses. In addition, the focus on analysis of probable failure modes will dictate exploration locations and depths.

Table 6-10 summarizes goals and the extent of site investigations in different phases of planning and design. The data required for each design phase will vary and be progressively more intense. Site investigation should be performed in phases for larger and more complex projects. This phasing will allow review of information obtained to inform further investigations, as well as allow more targeted investigation for specific design features as the design progresses.

Table 6-10: Site Investigation at Various Project Phases

Project Phase	Investigation Goals	Intensity of Investigation
Problem identification	• Existing conditions characterization	• Low: widely spaced explorations, may rely on geomorphologic and geologic mapping or historical reports.
Conceptual	• Inform planning level design; identify constraints	• Low: confirm expected geologic conditions and investigate potentially problematic geologic conditions.
Feasibility	• Inform feasibility analyses; identify fatal flaws	• Moderate: sufficient explorations to identify any fatal flaws and support feasibility of alternatives and establish comparative costs.
Final design	• Inform final design analyses	• High: sufficient characterization for detailed design.
Construction	• Confirm design assumptions	• As required to verify design assumptions.

Geotechnical considerations will vary depending on the type of levee project, as shown in Table 6-11.

Table 6-11: Geotechnical Considerations

Project Type	Consideration
New	• Heterogeneity and/or variability in geotechnical properties over varying distances could complicate soil characterization. • Presence of contaminants could be mobilized during ground disturbance. • Identification of usable borrow material. • Identification of areas where a groundwater cut-off is required to limit seepage during a flood can disrupt the natural groundwater flow. This could elevate the groundwater level and mobilize contaminants.
Modification	• Thorough understanding of internal structure and soil properties of the existing levee is required. • The existing levee may have a complex internal structure due to successive phases of historical raising or repair.

6.4 Levee Footprint and Features

The size of the levee footprint is determined by both physical constraints like available land on which to construct the levee and on levee performance considerations.

Understanding the space available for levee construction is critical in formulation of the project. Information on parcel boundaries, access corridor, and easement information should be collected and thoroughly understood. Limited space may result in designing a levee with steeper side slopes or a narrower crown. Levee performance factors such as slope stability, erosion, and seepage will determine if these adjustments to the levee design are feasible. In general, floodwalls are used when there is insufficient land to construct the required levee footprint.

For levees where performance considerations are not controlling factors, the selection of levee crown width and side slopes is controlled by many aspects such as type and ease of construction and safe access for maintenance. The inclusion of features to obtain co-benefits, such as walking paths or planting berms, may also impact the levee footprint.

Features included in a levee design also depend upon both performance and practical factors, as well as matters concerning the management of interior drainage. Foundation conditions may require stability berms or seepage control systems be included in the levee design. Hydraulic conditions may require erosion protection. Access requirements may require the inclusion of closure structures and space limitations may require the use of floodwalls instead of embankments.

Allowing vegetation, such as trees and shrubs, on levees has been long debated as they lead to uncertainties and can impact levee performance and access. Tree roots can create shortened and preferential seepage paths that may lead to levee failure. In stormy and windy weather, trees may blow over and create a hole in the levee, which could lead to significant erosion. Dense vegetation may also reduce visibility to the underlying levee, making inspections and floodfighting more challenging. Significant advances have been made over the past few decades in understanding how vegetation may not only impede but could also improve levee performance. Vegetation on levees can provide a benefit by enhancing ecosystem habitat and may actually increase levee performance by reducing soil erodibility and can stabilize riverbanks or slopes.

Levee construction can cut off natural flow patterns, preventing rainfall and other interior waters from flowing via natural drainage paths to the flood source. This interior water must be managed during floods, and either stored in dedicated ponding areas within the leveed area or evacuated from the leveed area via pump stations. During times when the levee is not loaded, gravity pipes through the levee may allow rain and other interior water to flow naturally to the flood source. These and other features that may be included in levee design are discussed further in **Chapters 2 and 7** and include:

- Embankment
- Floodwall
- Closure structure
- Seepage control systems
- Erosion protection

- Stability berms
- Pump stations
- Gravity pipes
- Instrumentation
- Natural and nature-based features

6.4.1 Hydraulic Evaluations

As discussed in sections 6.1.2 and 6.1.3, hydraulic modeling estimates the storm surge and wave heights that are used to determine the base levee height. One of the factors that influence wave heights is levee geometry. Flatter, longer slopes and/or the inclusion of berms to attenuate waves can decrease wave height. An iterative process of hydraulic modeling can be used to strike a balance between increasing the levee footprint and/or increasing the levee height to account for wave height.

6.4.2 Site Investigations

Seepage and slope stability performance of a proposed levee must be evaluated and addressed during plan formulation and design since both are common failure modes that can lead to levee breach. Geotechnical factors associated with these failure modes often determine the required size of the levee footprint, the shape of the levee cross section, and/or the necessary levee features. The potential for slope stability failures and detrimental seepage can both be ameliorated through flattening levee slopes or the incorporation of features such as relief wells, seepage/stability berms, or cutoff walls into the levee design. Slope stability and seepage performance must be evaluated and addressed during plan formulation as the slope adjustments and/or features required to address these failure modes can add significant cost and right-of-way requirements to the levee project. Computations to assess seepage and slope stability conditions can be found in EM 1110-2-1913 (USACE, 2000a).

6.4.3 Considerations for Vegetation on or Near Levees

It is important to understand expectations for vegetation management on or near the levee system during planning and into design and construction. Inclusion of vegetation into a levee design may be driven by a number of reasons including, but not limited to:

- Creation of habitat or improvement of habitat for special status species.
- Providing on-site mitigation for project impacts.
- Providing shading to reduce water temperatures.
- Providing shading to enhance recreational trails or areas adjacent to the levee.
- General environmental enhancement for aesthetic purposes.
- Improvement of water quality.
- Tribal cultural reasons.

- Engineering with nature-utilizing plantings to meet engineering objectives such as erosion resistance.

Meeting these needs early in the planning and design phases can greatly reduce issues later in the process. The ideal planting plan uses native species and optimizes access for floodfighting and maintenance for levees. Planning for the maintenance of the levee crown and landside slope should be accomplished to help ensure full access and visibility. Specific analysis would be required if there is a desire to have vegetation other than herbaceous plantings on the waterside of the levee. Consideration should be given to the habitat needs of target species, the hydrology and hydraulic forces that will be present in the floodplain, and any ancillary benefits (such as recreational benefits) that would likely be achieved. Designs should focus on the reestablishment of process (e.g., channel migration or point bar formation). There should be an understanding and acceptance that the area will and should change over time, as natural floodplains are dynamic. However, as proximity to the levee increases, planting plans should give increasingly greater priority to the stability and longevity of the levee structure. Plants which can reduce the overall maintenance burden for the levee, such as by reducing erosion, should be prioritized.

Since there are several hundred species of trees, and several thousand species of shrubs and other plants in the U.S., it is more practical to consider which species' characteristics are ideal for various planting zones around levees or for different levee reaches, rather than identifying specific species. Consideration of species characteristics should always begin with management objectives. Some management objectives to consider and how certain types of vegetation could affect those objectives include the following:

- What type of access is needed? Heavy equipment? Trucks? Pedestrian access?
- How often will the waterside operations and maintenance corridor need to be accessed?
- How will the waterside slope of the levee be inspected? By vehicle? Helicopter? Boat? Remote sensing? Drone?
- What is the maintenance budget and who conducts the maintenance?
- What types of burrowing animals are present in this area? Can the planting plan be optimized to discourage these animals?
- Are there other incidental uses that might drive vegetation selection choices?

6.5 Nonstructural Actions

Even though implementation of a levee project can reduce flood risk to a community, some level of uncertainty and residual risk remains. Nonstructural actions—including flood warning systems, evacuation planning, and community engagement—are necessary to manage levee risk once the levee is in place. The goal of nonstructural actions is to minimize this residual risk. As discussed in **Chapter 12**, increasing a community's awareness through education of the risks and benefits of a levee project, is a step toward preparedness before, during, and after a flood event. With increased awareness, individuals and communities can take action to reduce exposure and vulnerability of property to flood risk.

7 Plan Implementation

A major component of levee project formulation is developing a process for plan implementation. A levee project plan could have all the flood risk reduction potential to meet the identified objectives, but if it is not implementable by the community, it cannot progress to design and construction.

The division of roles and responsibilities with expectations for O&M, cost sharing, funding, permitting, planning, design, and construction schedules must be made clear for all invested parties. While much effort, as described in this chapter, is required to formulate a levee project, additional coordination and cooperation with the project team is needed to move beyond formulation of the plan.

As mentioned in section 5, the interaction between formulation, design, and construction is often iterative. Collaboration amongst the multi-disciplinary team is needed for successful plan implementation to foster smooth transitions between project phases. While a benefit-cost analysis to ensure the project is justified economically is a step toward reaching construction, it is vitally important to validate that the project is financially feasible. Additionally, a funding strategy should be established that includes means for covering construction costs and long-term O&M funding to ensure the project is completed and maintained such that the project reaches its intended design life, and beyond. Without long-term O&M funding, levee risk increases greatly over time. Note that once a levee plan is implemented, it should be revisited as conditions change, such as climate, development, updated floodplain information, floodplain management plans, or environmental regulations.

8 Summary

Once a community has established that their flood risk management strategy will include a levee, the generalized six-step planning process as described in section 3 should be used to arrive at the best alternative solution. Principles of levee formulation should include:

- Hold life safety paramount.
- Do no harm.
- Enhance natural resources.
- Make risk-informed decisions.
- Reflect community values, goals, priorities, and risk tolerance.
- Align with management of the floodplain.

Several best practices and considerations should be used by the plan formulation team not only in planning, but carried through to design and construction. Analyses of the study area is needed to formulate levee characteristics, which include engineering analyses, risk assessments, economic analyses, and environmental evaluations.

The goal of planning is to identify a cost-effective, technically feasible, and socially and environmentally responsible solution that meets project objectives. The levee plan formulation process should produce properly designed levee features intended to provide a certain level of flood risk reduction benefits to a community. The outcome of levee plan formulation passed on to the design team will be:

- Levee height
- Levee alignment
- Levee footprint and features
- Nonstructural measures

As conceptual ideas are refined and more is known about the study area, the level of effort for levee design increases and plan formulation decreases.

Having an implementation plan is critical to a project's success. The implementation plan should include how the plan will transition from formulation to design and construction, funding, real estate requirements, O&M needs, considerations for changes over time, and adaptive management options, at a minimum.

Related content associated with this chapter is included in detail in other chapters of the National Levee Safety Guidelines as described in Table 6-12.

Table 6-12: Related Content

Chapter		Chapter Title	Related Content
	1	**Managing Flood Risk**	• Flood risk management strategies
	2	**Understanding Levee Fundamentals**	• Types of levee projects
	3	**Engaging Communities**	• Engaging about levee projects
	4	**Estimating Levee Risk**	• Identifying flood risk • Vulnerability
	5	**Managing Levee Risk**	• Risk-informed decision making • Levee risk management
	6	**Formulating a Levee Project**	
	7	**Designing a Levee**	• Levee design considerations
	8	**Constructing a Levee**	• Construction considerations • Construction documentation
	9	**Operating and Maintaining a Levee**	• Operating and maintaining a levee
	10	**Managing Levee Emergencies**	
	11	**Reconnecting the Floodplain**	• Planning for levee removal
	12	**Enhancing Community Resilience**	• Incorporating community resilience