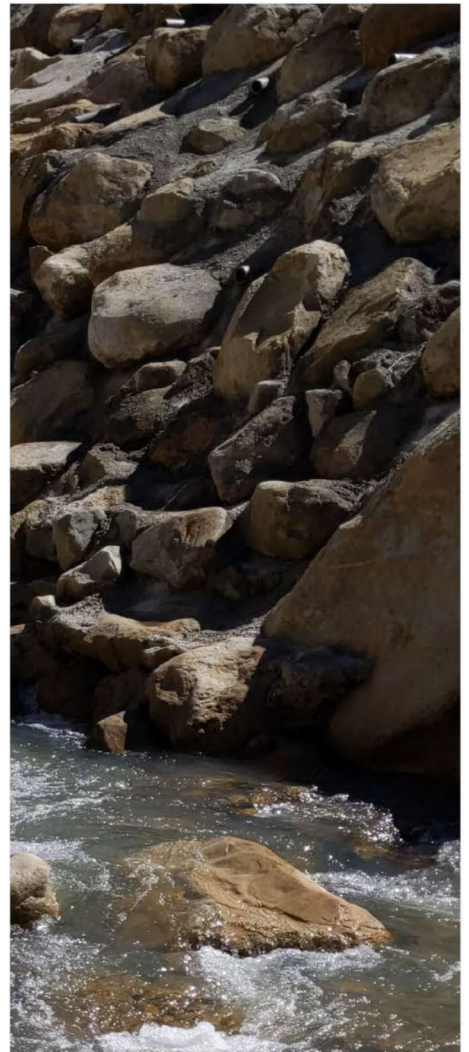
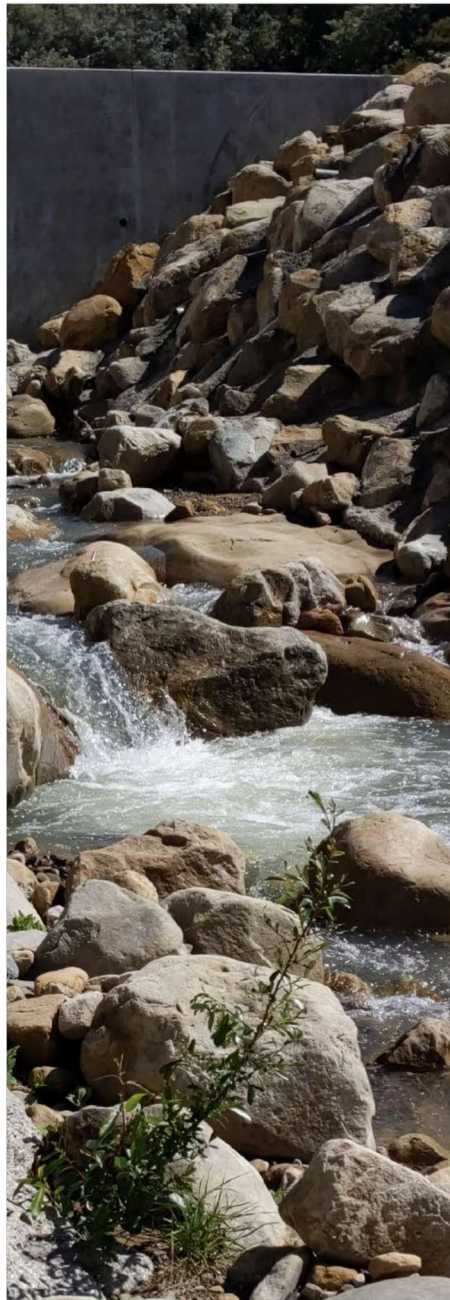
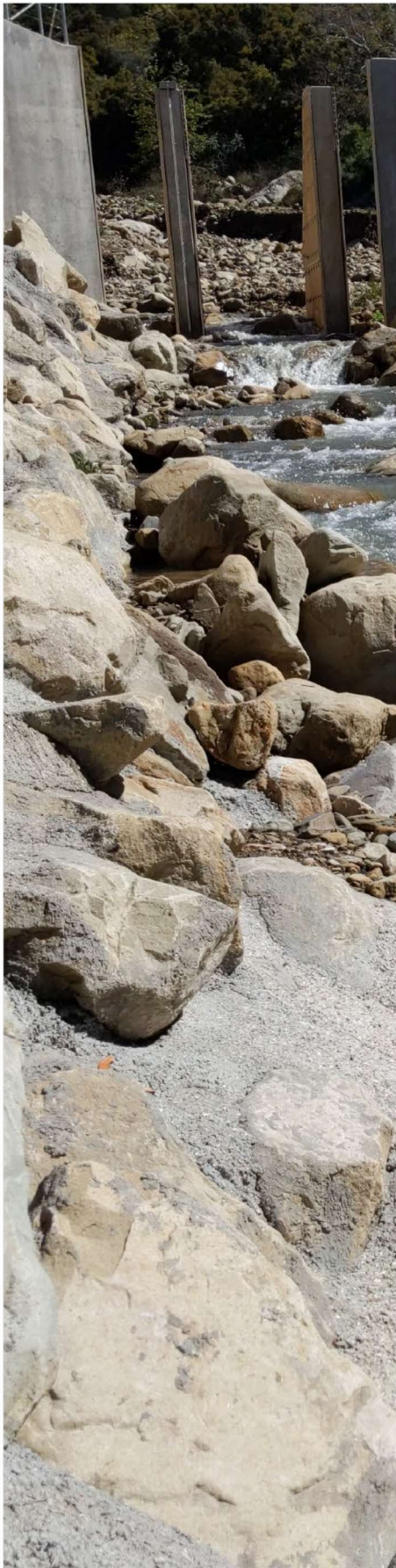




Beach Erosion Authority for
Clean Oceans and Nourishment
(BEACON)

Debris Basin Best Practices Manual

December 2024

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Acronyms

BAER	Burned Area Emergency Response
BARC	Burned Area Reflectance Classification
BEACON	Beach Erosion Authority for Clean Oceans and Nourishment
BRIC	Building Resilient Infrastructure and Communities
CDFW	California Department of Fish and Wildlife
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CFR	Code of Federal Regulations
DSOD	Division of Safety of Dams
DWR	Department of Water Resources
EAP	Emergency Action Plan
EDF	Energy Dissipation Factor
EIA	Environmental Impact Assessment
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ESA	Endangered Species Act
ESM	Engineered Streambed Material
FEMA	Federal Emergency Management Agency
FMAP	Flood Maintenance Assistance Program
HEC	Hydrologic Engineering Center or Hydraulic Engineering Circular
HMGP	Hazard Mitigation Grant Program
HMS	Hydrologic Modeling System
LWD	Large Woody Debris
NEPA	National Environmental Policy Act
NLCD	National Landcover Database
NLF	Nature-like Fishway
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OES	Office of Emergency Services
PDM	Pre-Disaster Mitigation
RAS	River Analysis System
SBS	Soil Burn Severity
SCS	Soil Conservation Service
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

1 OVERVIEW AND PURPOSE

1.1 Overview and Purpose

The Beach Erosion Authority for Clean Oceans and Nourishment (BEACON) is a California Joint Powers Agency (JPA) established in 1986 to address coastal erosion, beach nourishment and clean oceans within the Central California Coast from Point Conception to Point Mugu. The member agencies of BEACON include the Counties of Santa Barbara and Ventura as well as the coastal cities of Santa Barbara, Goleta, Carpinteria, Ventura, Oxnard and Port Hueneme.

The Central California Coast and the surrounding hillsides are susceptible to wildfires that can devastate the region, burn vegetation and result in unstable landscapes. When heavy rain events occur after these seasonal wildfires there are significant chances of debris flows through the steep canyons to the ocean shores. Typically, debris basins have been utilized as a control measure against these events. Often the debris basins were installed quickly after a wildfire by the United States Army Corps of Engineers (USACE) as an emergency effort. Traditional debris basin designs often consisted of graded open areas and a grouted rock embankment with a culvert to convey low flows. These designs resulted in impacts to the surrounding areas including fish passage barriers, reduced sediment transport that resulted in downstream scour, reduced sediment transport to the beaches, and a heavy maintenance burden to remove fine sediment from the basins after minor storm events.



Figure 1-1. Coastal hillsides during Thomas Fire.

Source: ABC News 2017¹

BEACON is providing this Debris Basin Best Practices Manual for reference to the surrounding communities based on knowledge and experiences gained on recent debris basin projects and debris basin modifications that were performed within Santa Barbara County. The objective is that, through the modification or application of new methods, future debris basin projects in the region could be implemented that both protect communities, minimize impacts to natural environments, and provide for improved sediment transport that feeds our beaches and oceans.

¹ Source: Fire Crews on the front lines in battle against California's raging Thomas Fire, 2017, <https://abcnews.go.com/US/fire-crews-frontline-battle-californias-raging-thomas-fire/story?id=51777996>

2 SITE SPECIFIC CONSIDERATIONS FOR DEBRIS BASIN DEVELOPMENT OR MODIFICATION

2.1 Site Conditions

2.1.1 Existing Terrain

The existing terrain at the site of a debris basin modification or new debris basin installation will significantly impact the design. The debris basin site is typically located through or adjacent to a creek or reach. The terrain in the upstream reach, basin reach, and downstream reach all present constraining factors in the design or modifications of a debris basin. Siting should consider the ability to effectively trap and store debris, control flow rate, ensure accessibility for maintenance, meet environmental regulations, and protect downstream communities. Each reach has unique geomorphologic and hydrologic conditions that influence the design and function of the debris basin.

Shallow slopes and floodplains make for effective basin reaches. Positioning the basin near natural slope breaks or transitions from steep to flatter terrain will allow for greater transport into and capture within the basin. Locations such as channel confluence points, the base of steep slopes, and expanding floodplains should be reviewed for feasibility. Grading around the basin site is typically required in order to maximize the effective storage volume of the basin within the constraints of the terrain and budget. This typically includes grading a flat benched area on one or both sides of a low flow channel through the basin reach and then sloping the sides of the basin to meet natural grade. The basin slopes should be stable and are dependent on geotechnical analysis or the surrounding soils but typically range from 2:1 to 4:1.

The upstream reach is where debris is generated within the system. The terrain in this area will determine the components of that debris and the energy it carries. In areas with steep upstream terrain, debris flows are often

fast-moving and carry heavy material such as boulders and trees alongside smaller sediments. A structural outlet designed to resist strikes and debris laden hydraulic loadings should be considered in these scenarios with a large enough opening in the outlet to allow finer sediments to pass to maintain basin volume for the capture of large destructive materials. It is key that the outlet size is designed according to an intended particle size to be captured. If the outlet sizing is not sufficient, an undesired backwater effect will be seen during larger storm flows. This will allow smaller grained material to settle and will result in increased maintenance efforts. Other factors that must be analyzed in conjunction with outlet size are basin area (extended floodplain) and pilot channel size.

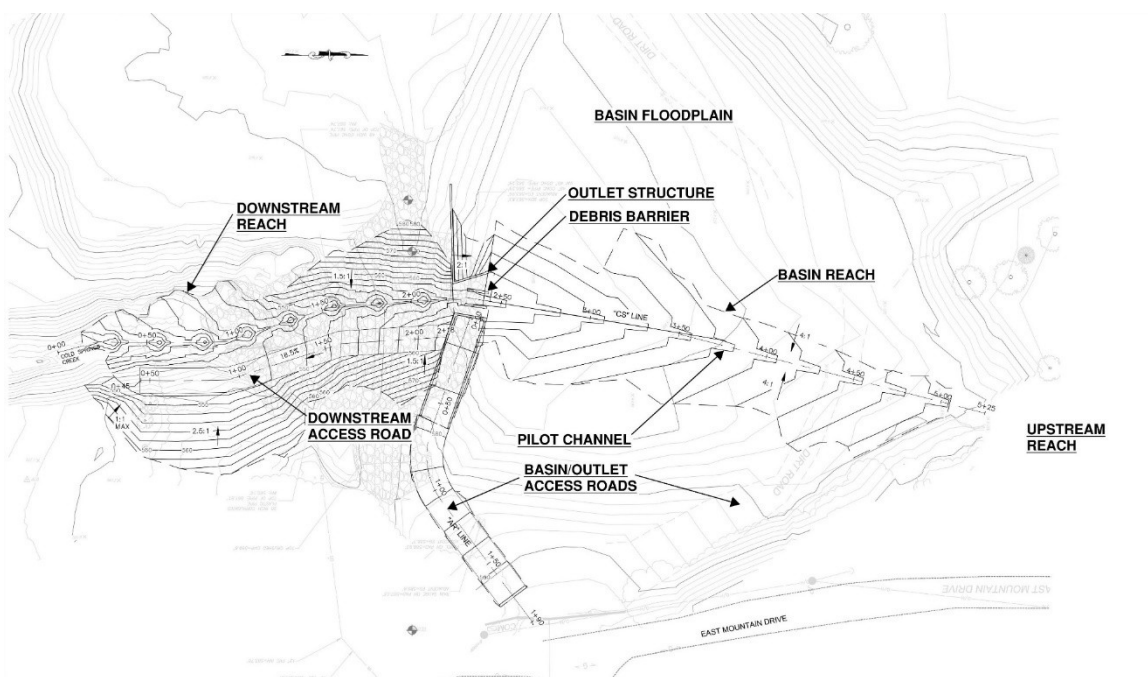


Figure 2-1. Common components of a debris basin.

Source: HDR 2023

In areas with shallower terrain in the upstream reach where debris flows consist of mostly gravels, sediments, and ash, sediment retention basins or sedimentation traps designed to capture finer sediments may be desirable.

These basins typically rely on earthen embankments or vegetation to retain debris.

If the downstream reach is through a developed area, the goal of the basin should be to remove debris and regulate flow in a way that prevents downstream damage from debris, flooding, and clogging of infrastructure to the maximum extent practicable. If the downstream reach is steeper than the basin reach, there may be risk of depriving the downstream reach of sediment due to capture within the basin which will result in erosion of the downstream channel. If the downstream reach is shallower than the basin reach, there may be risk of aggradation and reduction in downstream storage that can lead to greater risk of flooding. An outlet should be provided to restore the natural sediment transport processes of the channel post-construction to the extent feasible while meeting the objectives of the basin.

2.1.2 Right-of-Way

In developed areas and hillside communities near the coast, acquisition of land from private owners for construction of a new debris basin often bears the highest cost for a new project. Potential siting of new debris basin locations should focus on areas of repetitive debris flow damage as these are often locations of natural debris deposition.

For debris basin modifications, existing right-of-way and land ownership will often constrain the potential volume of the debris basin. Coordination with adjacent landowners on potential land purchase or easements should be part of early coordination efforts. A phased design and construction approach is also an option while additional right-of-way is being pursued.

2.1.3 Geotechnical Analysis and Constraints

A geotechnical investigation and analysis of the project site should be conducted to determine modeling and structural design parameters for the debris basin, channel, proposed structures, and the outlet.

A thorough pebble count should be taken in the upstream reach, basin reach, and downstream reach. Knowing the undisturbed particle distribution on the surface helps determine streambed roughness and the natural distribution for sediment transport. The information is also valuable for developing gradations of engineered streambed materials to mimic the creeks natural gradation curve with or without additional armoring. If the transport has been disturbed by a recent debris flow, the pebble count will provide valuable information on the size of material the basin should be designed to capture. The pebble count sizes also provide an approximate particle size range for the analysis of incipient motion and sediment transport for analyzing the impacts of the basin and outlet structure.

Borings and soil laboratory testing will help determine design parameters for structures with sub-surface elements such as retaining walls, debris walls, debris racks, and energy dissipation structures. The soil tests are helpful in determining if on-site material is appropriate for use as fill and if the strength of the underlying material is appropriate for bearing the weight of the structure and hydraulic loadings.

The following should be considered when conducting the geotechnical analysis:

- A literature search for all readily available published geologic and geohazards information at and in the near vicinity of the project site.
- Obtain copies of all readily available studies performed at or in the near vicinity of the project site.
- Visit the site and mark out with wooden stakes the proposed boring locations and call Underground Service Alert (USA) a minimum of 72 hours prior to the start of field investigation work.
- Perform a pebble count.
- Pay all fees and obtain a well construction/destruction (boring) permit from Environmental Health Services.
- Perform soil borings at the project site and if possible at a burned location upstream of the proposed basin, backfill as per county requirements.

- Perform soil laboratory testing on recovered representative soil samples to obtain parameters for analysis and design, including: thickness of the hydrophobic layer, soil type, stratification, gradation curve, moisture content, hydraulic conductivity, porosity, Atterberg limits/plasticity, cohesion, angle of internal friction, corrosivity, depth to bedrock and groundwater, bearing capacity, liquefaction, and degree of weathering.

2.1.4 Sediment Loading

The presence of various rock and sediment sizes in a creek plays a key role in shaping the design approach. A common goal of a debris basin is to maintain post-construction sediment transport as similar to the natural conveyance of the creek as possible during small storms while allowing for capture of large rocks, detention of debris waves, and capture of large woody debris during larger storms or post-burn conditions.

In general, targeting finely graded sediment and gravel loads requires a more constricted outlet to reduce flow velocity and capture smaller materials. Targeting coarser graded gravels, cobbles, and boulder loads requires a less constricted outlet to allow the large materials further into the basin and smaller materials a continuous flow path. Debris flows are often bulked with large amounts of sediment and ash in addition to more coarsely graded material and organic debris. To reduce the risk of damage to downstream communities, it requires a balance between capturing large destructive materials and allowing for the passage of smaller materials.

2.1.5 Fish Passage Requirement

Fish passage requirements play a critical role in the design and modification of debris basins, particularly in areas where streams serve as migration routes or habitats for fish species. Federal and state regulations mandate that fish passage be maintained or restored in critical habitat streams where fish migration is essential, such as for anadromous fish (e.g., salmon and steelhead trout). Providing volitional fish passage can significantly impact the design of new debris basins or the modification of existing ones, requiring

the integration of features that allow fish to freely navigate both upstream and downstream through the basin to reach habitat during different parts of their life cycles.

If the stream through the project site is a migration route, it is best to begin coordination with regulatory agencies within the early phases of the project as their design requirements will affect method of design. Depending on slope, project terrain, and proposed improvements, stream simulation or hydraulic design methods may be options to meet regulatory requirements.

The goal of the stream simulation approach is to mimic the natural streambed and flow conditions through the debris basin. This method is helpful for maintaining natural sediment transport and flow variability. It typically involves recreating the natural substrate and flow patterns found upstream and downstream of the debris basin. The *California Salmonid Stream Habitat Restoration manual* (CDFW 2018) and *Habitat Typing* (NCRCD 2017) are available to guide identification of habitat to be recreated through the basin reach.

The hydraulic design approach focuses on engineering flow velocities and depths that are suitable for fish migration based on species-specific swimming capabilities, stage of life, and dimension. This method is less natural than stream simulation but can be applied in situations where precise flow control is necessary to maintain passable conditions. Hydraulic designs often include engineered structures such as retaining walls and grouted rock elements.

The National Marine Fisheries Service (NMFS) and California Department of Fish and Wildlife (CDFW) hold authority in the protection of marine, anadromous, and endangered fish species through the Endangered Species Act (ESA) and California Endangered Species Act (CESA). The following resources are available to determine if the project is within endangered species habitat:

- NOAA Fisheries – National ESA Critical Habitat Mapper (Online Open Source)
- CDFW – California Natural Diversity Database (Online Open Source)
- Or contact the agency directly

If the project is determined to be within the habitat of an anadromous California fish species, the following guidance documents should be reviewed in order:

- Step 1.0 NOAA Fisheries West Coast Region Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change (NOAA 2022a)
- Step 1.1 Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings (USFS 2008)
- Step 1.2 Part XII Fish Passage Design and Implementation (CDFW 2009)
- Step 2.0 NOAA Fisheries Pre-Design Guidelines For California Fish Passage Projects (NOAA 2023a)
- Step 3.0 NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual (NMFS 2022b)
- Step 4.0 NOAA Fisheries Guidelines for Salmonid Passage at Stream Crossings in California (NOAA 2023b)

2.1.6 Environmental Considerations



Figure 2-2. Example of species to protect (amphibians, reptiles, fish).

Source: Santa Barbara County Flood Control District 2023

When designing a new debris basin or basin modification, environmental considerations are critical to minimize ecological impacts while maintaining the primary function of debris and flood control. These considerations involve not only legal requirements but also best practices for protecting wildlife, habitats, and water quality. Several key environmental aspects include construction work windows, dewatering requirements during construction, species considerations, and channel design approach.

Construction work windows are specific periods during which construction activities are permitted to minimize impacts on sensitive species or ecosystems and prevent risk to crews from floods during the rainy season. The timeframes are often set by regulatory agencies such as NMFS, CDFW, and the California Regional Water Quality Control Board (RWQCB), to avoid disrupting the critical life stages of fish and bird species, such as spawning, migration, or nesting and to protect water quality. These work windows will limit the time available for construction, especially in areas with migratory fish or bird populations. Careful scheduling is required to ensure construction is completed within the designated timeframe. The work windows may also affect the timing of maintenance activities outside of emergency conditions.

Dewatering involves temporarily removing water from a stream or work area to create conditions dry enough for construction. It can disrupt aquatic habitats and water quality if not managed carefully. Fish screens may be required to prevent trapping of protected species. Sediment control measures should be incorporated to prevent harmful effects on aquatic ecosystems. In the case of temporary flow diversion, when water needs to be redirected around the work area, the design may need to include temporary bypass channels, pumps, and pipes to allow for continuous flow and maintain passage of aquatic organisms during construction.

Debris basins can potentially affect a range of species beyond fish, especially if they are located in sensitive habitats such as wetlands, riparian zones, or

areas with endangered species. Other species considerations include protecting terrestrial wildlife, amphibians, and plants that may be affected by non-emergency construction, maintenance, and operations. To satisfy these considerations, design elements such as buffer zones, restricted areas for vegetation removal, or habitat restoration efforts may be required. For terrestrial species, wildlife crossing or fencing to prevent animals from becoming trapped in the basin may be required. Design should plan for revegetation and erosion control in riparian zones so that they continue to provide an ecological benefit.

Another key environmental consideration is to avoid unnecessary disruption and maintenance of existing creeks and to integrate designs that mimic the natural channel. When possible, designers should prioritize Stream Simulation and Nature-like Fishways (NLF) before considering more rigid hydraulic designs such as fish ladders with solid concrete weirs.

2.1.7 Utility Coordination

Above ground and underground utilities may be located at or near a potential or existing debris basin project site. Potential utility conflicts may include gas, electric, communication, sewer, stormwater, and fresh water. If the site selected for the project was previously developed, there may be buried man-made objects beneath the surface. Research and survey for buried man-made objects such as septic, wells, cisterns, propane, and foundations. This may become the responsibility of the contractor during construction.

Earthwork to form the basin and any sub-surface structures may conflict with existing or abandoned utilities and buried man-made objects. The utilities will need to be removed or relocated based on coordination with utility providers and private owners.

There may be scenarios where utilities are not in conflict with earthwork but are at risk of damage from debris flows. It is important to identify all potential utilities upstream or downstream that are at risk of scour and

debris/rock strikes. Above ground utilities that cross creeks at bridge crossings can be particularly vulnerable to debris flows that have the potential to block or damage bridge crossings. At risk utilities should either be protected or relocated based on coordination with the utility providers.

2.1.8 Public Safety and Surrounding Development

The design and placement of debris basins should prioritize public safety and account for the impact on surrounding developments, both upstream and downstream, as well as those adjacent to the basin. Understanding the relationship between debris flow inundation areas and existing land uses is critical to mitigating risk to life, property, and infrastructure.

Analysis of extreme condition scenarios such as large storm event after a fire or debris flow events when the debris basin capacity is reduced should be performed so that flow patterns from the overtopping of the outlet structure or the debris basin banks can be identified. Design of the debris basin should aim to direct potential overtopping towards less vulnerable areas, often over the outlet structure. Flows overtopping the debris basin banks could create new and unpredictable overflow paths and lateral debris movement through areas unprepared for concentration flows.

A detection or warning system should be considered to warn downstream communities and adjacent communities of potential overtopping. The basin should be designed to overtop or exceed without failing to prevent releasing a debris wave into downstream communities.

2.2 Regulatory Agency Coordination

Each level of government contributes to various aspects of a debris basin project. The successful development of a debris basin requires coordination between federal, state, and local agencies to secure funding, ensure regulatory compliance, incorporate public safety measures, and provide adequate emergency preparedness and response.

2.2.1 Federal

The U.S. Army Corps of Engineers (USACE) plays a large role in debris basin permitting/design through the Section 404 permit process and debris clearing through emergency contracts, strategic coordination, and technical guidance. They offer pre-arranged contracts for rapid response, helping clear and manage debris post-disaster. Additionally, USACE collaborates with local and federal agencies, including FEMA, on coordinated efforts for clearing roadways, waterways, and public areas. Their support includes both immediate emergency operations and design-focused guidance for hydraulic and geotechnical engineering of debris basin infrastructure.

If the debris basin reach is part of a creek containing federally protected fish species, the National Oceanic and Atmospheric Association's (NOAA) National Marine Fisheries Service (NMFS) and the United States Fish and Wildlife Service (FWS) play a role in ensuring the project complies with the Endangered Species Act (ESA). These agencies are consulted during the USACE permit process if the project area may contain federally listed species or is within critical habitat jurisdiction. NMFS involvement focuses on ensuring that the basin project complies with federal regulations aimed at protecting anadromous species and their habitat. Coordination with NMFS should begin in the early phases of the project as NMFS opinions could inform and affect design.

The Federal Emergency Management Agency (FEMA) plays a large role in debris basin design and coordination, particularly through funding, technical assistance, hazard mapping, floodplain mapping, and disaster mitigation planning. Design of the debris basin and the potential impacts to the surrounding floodplain should be coordinated with FEMA once a preliminary design is determined and hydraulic modeling of potential impacts are complete.

2.2.2 State and Local

When designing and implementing a debris basin, especially if it reaches a size that categorizes it as a dam under regulatory definitions, coordination is required with state agencies, particularly the California Governor's Office of Emergency Services (Cal OES), California Department of Fish and Wildlife (CDFW), California Regional Water Quality Control Board (CRWQCB), and California Coastal Commission (CCC) if the project is within the Coastal Zone. If a debris basin meets the regulatory definition of a dam (typically determined by its height, capacity, or potential impact on downstream populations), it must comply with California's Dam Safety Program requirements, overseen by Cal OES in partnership with the California Division of Safety of Dams (DSOD). This classification triggers strict design, construction, and operational standards to ensure structural integrity and public safety. These agencies play key roles in ensuring that debris basins meet safety, environmental, and operational standards essential for public safety, ecological integrity, and regulatory compliance.

For debris basins that reach dam classification, an Emergency Action Plan (EAP) is required. This plan, developed in coordination with Cal OES and the DSOD, outlines steps for emergency notification, evacuation routes, and response protocols in the event of structural failure or overtopping. Cal OES will typically conduct review drills and assessments of the EAP to verify that all emergency response measures are effective and understood by local authorities. The EAP is essential in high-risk areas with populations or critical infrastructure located downstream.

The California Environmental Quality Act (CEQA) requires agencies to assess the environmental impacts of new debris basins. The CEQA review ensures the project minimizes harm to wildlife, habitat, and public spaces. The CEQA process often involves producing Environmental Impact Reports (EIR) for the proposed project.

The California Department of Fish and Wildlife (CDFW) reviews the debris basin project to analyze compliance with the California Endangered Species

Act (CESA) and a Streambed Alteration Agreement (SAA) will likely be required. If the project affects state-listed species or their habitats, the agency may require mitigation measures such as habitat restoration or fish passage facilities. CDFW also review projects for impacts to anadromous fish species which are protected by federal and state law.

The California Regional Water Quality Control Board (CRWQCB) requires that projects obtain a 401 Water Quality Certification if they involve discharges of dredged or fill material to waters of the United States including wetlands and other water bodies. Such discharges may result from navigational dredging, flood control channelization, levee construction, channel clearing, fill of wetlands for development, or other activities. These projects involve the removal or placement of soil, sediment, and other materials in or near water bodies and require Corps permits under CWA Section 404.

The California Coastal Commission requires a Coastal Development Permit (CDP) for project construction and maintenance within the Coastal Zone. If the project falls within CCC retained jurisdiction then the permit application is submitted directly to the CCC for approval. If the project is not within retained jurisdiction and the local government jurisdiction that the project falls under has an approved Local Coastal Program, the CDP would be applied for through that City or County process.

At a local level, your local flood control district is typically responsible for identifying the need for debris basins, conducting feasibility studies, initiating the process to secure funding, and obtaining design and construction documentation. Flood control, generally responsible for maintenance and operations of the basin, may defer when post-disaster relief is required for debris removal. A planning and development department generally is involved to assess that debris basin projects comply with local planning laws, including setbacks, development restrictions near flood zones, and habitat protection ordinances. They collaborate with the flood control district to issue permits and approve designs that align with local and state regulations.

Proposed debris basins located within Special Flood Hazard Areas shown on FEMA National Flood Insurance Rate Maps may need to comply with local Floodplain Management Ordinances.

Zoning restrictions may determine where debris basins can be located and whether adjacent areas should be restricted from development due to flood or debris flow risks. Local agencies may also oversee community outreach and engagement to inform residents about the purpose of debris basins, construction schedules, and long-term maintenance impacts.

Local emergency services, such as fire departments, public works, and sheriff's offices, should be involved in debris basin projects. These agencies help coordinate emergency response plans for post-debris flow scenarios, ensuring that evacuation routes and public safety measures are in place during and after significant storms.

2.3 Maintenance and Operations Considerations

Debris basin design should be developed with maintenance staff involvement and input. The inherent nature of debris basins require regular maintenance and at times emergency maintenance. Elements of the debris basin design can be developed to help reduce regular maintenance needs and to assist when maintenance is required.

2.3.1 Pilot Channels

Pilot channels are narrow channels constructed within the debris basin to concentrate flows and velocities that will transport sediments toward the basin outlet structure during smaller storms and normal flow conditions. Pilot channels tend to evolve and meander over time due to reoccurring small storms. Potential migration of a pilot channel should be considered during design. Large boulders, buried large woody debris, or other channel forcing features can be implemented to influence pilot channel paths but any pilot channel or manmade channel in these areas should account for channel evolution over time.



Figure 2-3. Basin pilot channel.

Source: Santa Barbara County Flood Control District 2023

Pilot channels should be regularly inspected to assess any trends in migration or meandering. If deposition or erosion caused by the pilot channel migration poses a risk to the debris basin banks, maintenance access, underground utilities or other elements then newly placed forcing features may be required to redirect the pilot channel. Realignment and regrading of a pilot channel will likely be necessary to restore the optimal flow path and restore natural sediment transport downstream after a large event results in debris and rock deposited in the basin.

2.3.2 Maintenance Access

Adequate maintenance access is required to allow crews and equipment to easily reach the debris basin for routine inspection, debris removal, and emergency operations. After a debris flow event, maintenance ramps may require repair prior to gaining access for maintenance operations. Earthen ramps tend to erode or become buried and can be reformed using onsite material. Heavily textured concrete ramps may be necessary for

maintenance access at locations with a steep approach into the basin but may become buried during a debris flow event and must be exposed without causing additional damage to the structure.

The access leading into the basin must be capable of supporting heavy equipment such as excavators, dump trucks, and similarly sized equipment. Steep slopes or embankments used to form the maintenance access pathways may require rock slope protection or retaining walls to protect from erosion.

Barriers, fencing, and signs may be placed along the access route to ensure public safety and prevent unwanted access.

2.3.3 Standard Maintenance Operations

Standardizing maintenance operations requires implementing routine inspections and actions necessary to keep the basin functional during non-emergency conditions. Although the basic maintenance strategies are the same for all basins, specific actions are often required for each depending on location and design. An inspection schedule should be prepared for assessing the condition of the basin, outlet structure, pilot channel, structures, and surrounding area. The inspections should focus on identifying sediment accumulation, vegetation growth, erosion, and damage to any structural elements.

Periodic debris removal may be required to maintain the basin's capacity outside of emergency conditions. This includes removal of sediments, rock, and organics. The frequency of debris removal depends on storm frequency, burn severity, and basin design. An open outlet structure designed to pass smaller rock and sediment will reduce the frequency of debris removal required.

In general, vegetation growth in the debris basin is beneficial to stability, deposition, and habitat. Excessive vegetation growth, however, can reduce basin capacity and obstruct flows. Routine clearing of vegetation in the pilot

channel and around the outlet structure will help maintain basin function and natural sediment transport. Standard maintenance may also include minor repairs to project elements such as grouted rock and any structures essential to the operation of the basin.

2.3.4 Emergency Maintenance Operations

Emergency maintenance operations are activated in response to sudden or extreme debris flows, floods, fires, or other events that threaten the basin's capacity or function with ongoing risk of additional debris waves. Debris basin maintenance crews must coordinate with local emergency services to ensure that access routes remain clear, evacuation plans are in place, and any immediate safety hazards are addressed.

Maintenance and emergency response teams must quickly mobilize to clear debris that has filled the basin or clogged the outlet structure. A window of safety is required to mobilize without risk of teams being inundated by the anticipated flow event. Large material such as trees and boulders will likely be present.

Emergency repairs may be needed if damage to the basin's embankment or outlet structure is detected. Reforming the pilot channel is not a priority during emergency conditions. Instead, desilting, erosion control, embankment stabilization, and outlet structure repairs should be prioritized to prevent overtopping or failure of the basin.

2.3.5 De-silting Considerations

Debris and sediment removal from the basins may be necessary immediately after a large storm flow if it is early in the rainy season or during the fall maintenance season if a spring inspection identifies an unacceptable amount of debris and sediment in the basin. The acceptable volume of debris and sediment that remains after the rainy season will differ from basin to basin due to different sized facilities, however, when a basin's effective volume is reduced by approximately 25 percent, it should be cleaned out.

De-silting operation will also take place after a significant fire in the watershed when vegetation and debris should be removed in anticipation of expected increased post-fire storm runoff. During this process it is key that the established pilot channel is not disturbed, if feasible. Leaving the pilot channel will ensure smaller grained sediments are transported through the basin during low flows and avoid depositing these small sediments in the basin leading to unnecessary increased maintenance and associated costs. Based on the basin maintenance plan and severity of burned watershed, vegetation may be left on the banks of the pilot channel to continue providing habitat to wildlife species and lessen erosion potential in moderate flows.



Figure 2-4. De-silting post-debris flow.

Source: Santa Barbara County Flood Control 2023

After de-silting maintenance, the basin and channel should be roughened to create microtopography that will encourage re-establishment of aquatic habitats over time. Pools, steps, riffles and other fish passage features should be recreated in the pilot channel if they were removed during maintenance.

Locations adjacent to the debris basin but outside of potential overflow paths can be used to store large rocks and boulders that may be useful in maintenance activities after the threat of an eminent flow event has passed. Facilities or locations for depositing removed sediment should be identified and coordinated before each rainy season.

2.3.6 On-going Monitoring

Public Resources Code Section 21081.6 and CEQA Guidelines Section 15091(d) requires the adoption of a reporting and monitoring program for debris basin projects and conditions adopted to mitigate or avoid significant effects on the environment. In addition to the bi-annual monitoring inspections, there should be an inspection of the basin and surrounding area annually to determine maintenance needs.

A biologist should monitor maintenance activities to ensure that the appropriate methods and limits are used. These activities include brushing, herbicide application, channel shaping, desilting, bank stabilization by placing fill or grading banks, bank protection construction or repair, grade stabilizer construction or repair, pilot channel construction, and access ramp construction.

A biologist should also monitor earth and vegetation disturbing maintenance activities located at and adjacent to locations where sensitive species are known to occur. The need for monitoring and the areas to be monitored shall be determined during an annual field assessment in the spring. The objective of the monitoring is to ensure that key habitat features or species locations are avoided.

2.4 Setting Design Goals for a Debris Basin Project

2.4.1 Flood Protection

Providing flood protection to downstream communities is a benefit of debris basin design. The flood protection can come in the form of reduced

downstream inundation as a function of detaining debris flow surges while metering the outflow with an appropriately sized outlet and/or the benefit of removing large hazardous debris from debris laden flows that have the potential to clog downstream creek crossings or result in damage to properties and infrastructures.

FEMA's National Flood Insurance Rate Maps and Flood Insurance Studies should be used to determine if a debris basin is within or near an existing floodplain. Effective floodplain models can then be requested from FEMA, if available, to analyze potential floodplain impacts of a proposed or existing debris basin. When constructing in a regulated floodplain or floodway, the basin should not increase downstream water surface elevations.

Mapping of debris flow inundation limits for historical storm events and mapping of existing floodplains are valuable information for determining the impact of a new basin or modification. Once obtained, it can be used to help calibrate hydraulic design and sets a reference for comparison.

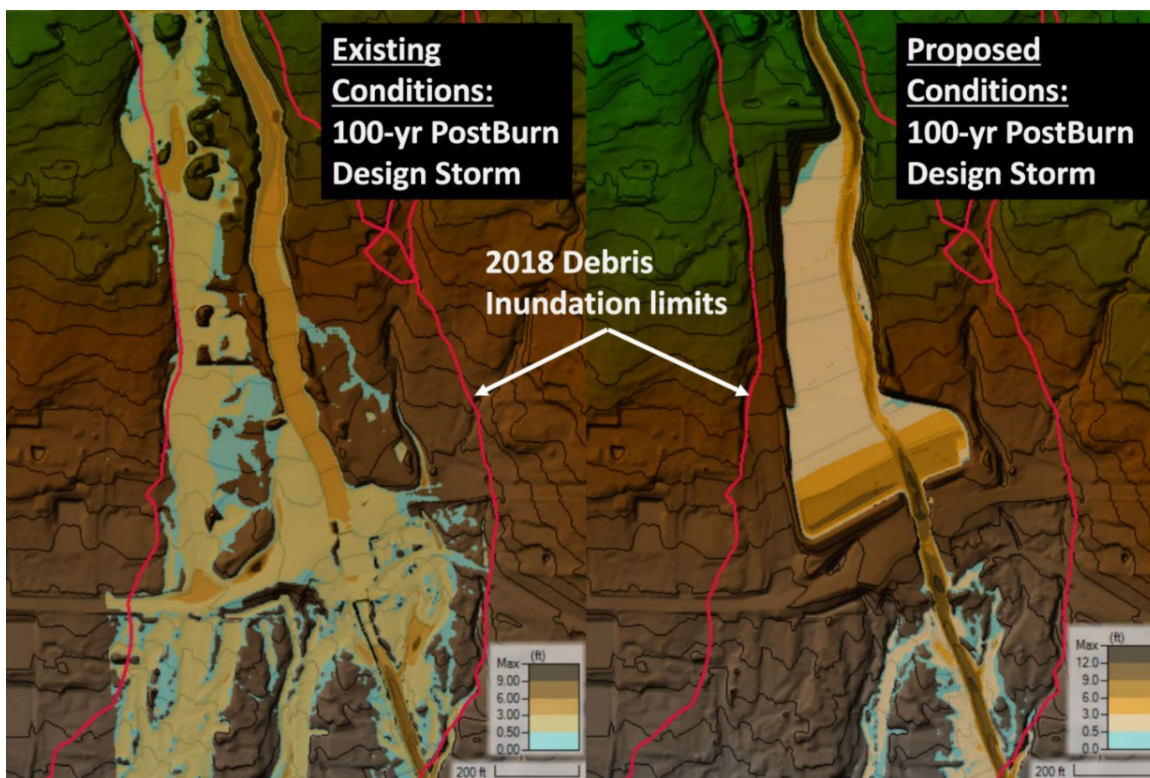


Figure 2-5. Mapping of inundation limits vs. design storm.

Source: HDR 2023

Determining the design storm for a debris basin design or modification will often depend on competing factors of the design such as the basin volume available, the outlet structure height that can be achieved, the outlet opening size, and the desired size of large debris capture. There is also the consideration of a watershed under regular conditions (pre-burn) or under conditions where a wildfire has burned the majority of the watershed (post-burn).

Under most debris basin designs, structural elements should be designed to withstand a 100-year storm event under post-burn conditions. A 100-year storm event under pre-burn conditions is more typically used for floodplain analysis and design with a typical design goal of not overtopping the outlet structure. More extreme events are often too infrequent and large for practical design consideration.

2.4.2 Debris Basin Volume

The ability of a debris basin to capture and retain debris is related to the capacity of the basin and is diminished as the basin fills. As such, each project should maximize basin capacity within the space available. The available space and slope at the project location will constrain effective basin volume. Effective basin volume is the minimum storage volume of a basin after which overtopping of large materials will occur. Effective basin volume is defined by the volume between the post-burn design flood and finish grade within the basin.

Steeper basins tend to have a shallower post-burn water surface elevation at the entrance to the basin as opposed to the outlet structure where the constriction causes backwater which induces a rise. Every basin will have its own set of complex hydraulics which affects capacity prior to overtopping. Maximizing transport of smaller sediment gradation sizes through the basin will allow for more basin volume to be retained and available for larger materials that can be more hazardous moving through the downstream reach.

Where proposed debris basins are intended to be designed to a prescribed criteria, basin volume should be based on anticipated debris generation. Debris basin design criteria and anticipated debris generation should be determined by established engineering manuals and resources provided by well-known originators such as USACE and NRCS or local requirements. Some well-established references on the subject are provided in Section 7.7.

2.4.3 Sediment Transport and Capture

The information collected during geotechnical analysis and survey can inform rock size and sediment loading. Analysis of this information should provide the gradation of material which will transport in the upstream and downstream reaches. The upstream reach is often steeper and carries larger material than the basin reach. The goal should be to capture the larger material of the upstream reach while allowing the transportable gradation

from the downstream reach to continue through the basin during normal non-emergency operation. If flow velocities and depths through the basin are not strong enough to transport the necessary sediment gradations downstream, a pilot channel can be designed through the basin to concentrate flow and improve sediment transport.

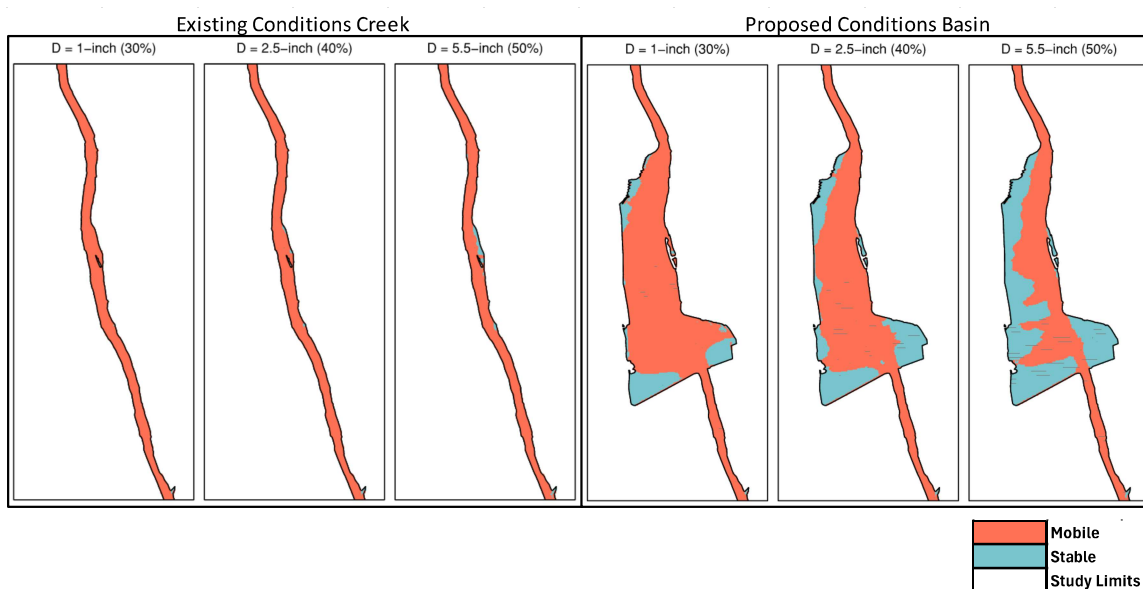


Figure 2-6. Spawning gravel mobilization example.

Source: HDR 2020

The outlet structure should be sized appropriately to pass the natural downstream transportable gradation. Failure to pass this gradation can lead to significant downcutting as the downstream reach becomes starved of sediment and gravels.

Structures within the basin such as debris racks or debris walls should be designed to capture rocks large enough to block the outlet structure before they reach the outlet to allow for continuous flow through the outlet structure and to prevent premature filling of the basin with finer sediment deposition.

2.4.4 Large Woody Debris Capture



Figure 2-7. Debris rack in operation.

Source: Santa Barbara County Flood Control District 2023

The height and width of trees in the upstream reach will inform the largest expected woody debris size. Historical records of debris that flows through the area is also an important reference. Basins should be designed to trap large woody debris prior to it blocking the outlet and potentially trapping large amounts of smaller grained sediments in the basin. Debris racks and other large woody debris capture devices are helpful in capturing material before it prematurely clogs the outlet structure.

As these devices become inundated with debris, there will be a potential increase in water surface elevation and velocity hotspots which can induce scour, especially when the device is near a bank or other erodible feature. The capture devices will need to resist rock strikes and large hydraulic loadings. The load increases proportional to the flow rate and debris volume. A taller capture device often requires exponentially stronger design elements to prevent the structure from buckling as opposed to one designed for

smaller flows. These systems can also be useful for capturing large rocks early in the basin before they can damage or clog the outlet.

3 DEBRIS BASIN DESIGN OPTIONS

3.1 Hierarchy of Difficulty

There are many approaches for the design of fish passage facilities for debris basins, each with varying levels of complexity, cost, and regulatory scrutiny. The hierarchy of difficulty in fishway design ranges from naturalistic approaches like Stream Simulation Method (SSM) and Nature-Like Fishways (NLF) to more engineered approaches involving hydraulic analysis and hard structures. Naturalistic designs are less costly and simpler to implement, while engineered, hard-structure designs require intensive analysis and are more likely to face regulatory challenges and higher costs. In debris basin design, stream simulation and NLFs are the preferred options for both simplicity and regulatory efficiency, as they mimic natural systems and have minimal impact on aquatic habitats.

SSM is designed to mimic natural stream environments, facilitating fish passage with minimal artificial intervention. These fishways use natural materials, like rocks and logs, and replicate natural stream gradients and flow conditions, based on natural reference reaches upstream or downstream of the project site. SSM is usually the least costly and easiest to implement, as it typically requires minimal hydraulic engineering. SSM is constructed using natural materials in ways that blend into the surrounding habitat and can use native material in design. SSM closely resembles natural channels, making it appealing to regulatory agencies. This natural design minimizes the likelihood of objections and accelerates regulatory approvals, as it maintains habitat continuity and reduces concerns over fish passage impacts. Because this method mimics the existing upstream and downstream environments, they often require less design time. Regulatory bodies appreciate these designs as they reduce potential habitat disruptions, translating to less time spent on environmental reviews and lower costs associated with regulatory compliance. SSM may not be suitable in areas with steep gradients, high flow velocities, or where precise control of water

flow and sediment is necessary, as it relies on natural flow conditions which can vary seasonally.

NLFs are a step above SSM in design complexity, involving the recreation of the natural streambed characteristics (substrates, slopes, flow depths, and velocities) found in the original stream. This approach involves engineering a channel that behaves similarly to the natural streambed while maintaining passage for aquatic organisms. NLFs are slightly more complex and costly than stream simulation, but remain within the lower end of design difficulty. Engineering work is required to achieve the correct slopes, substrate composition, and flow conditions, but the design retains a naturalistic quality that reduces regulatory concerns. Similar to stream simulation, NLFs are favorably viewed by regulatory agencies because they closely mimic natural habitat types. NLF design minimizes disruptions to aquatic habitats, facilitating a quicker approval process. Though it involves some engineering, NLFs typically requires less time for regulatory review than hard structures or hydraulic designs. Stream simulation and NLFs allow for sediment transport and support fish movement without drastically altering flow patterns. Stream simulation and NLF design may be challenging in areas with extremely steep or unpredictable flow conditions where mimicry of natural channel morphology isn't feasible, or in basins requiring higher precision in controlling sediment and debris.

Hydraulic analysis and the use of hard structures represent the most engineered, intensive approach to fish passage facility and debris basin design. This category includes the use of features such as retaining walls, debris flow breakers, grouted structures, culverts, and structural outlets or embankments. The goal is to precisely control water flow, debris movement, and sediment transport, with fish passage incorporated as part of a highly regulated hydraulic system. Hard structures require extensive hydraulic analysis, modeling, and structural engineering to withstand high flows and large debris. This makes them the most difficult and costly option, as they require significant time, resources, and specialized engineering knowledge. Regulatory agencies typically scrutinize hard structures closely due to their

greater impact on natural habitats and potential for disrupting aquatic ecosystems. This level of regulatory review can lead to prolonged approval times and, subsequently, increased costs due to the need for detailed environmental assessments and the possibility of design modifications. It is best to keep hard structures out of fish passage flows to avoid additional regulatory delays. Due to the engineering and hydraulic analysis involved, the design process is often much longer and requires careful modeling of flow, erosion potential, and debris impacts. Approvals may be delayed as agencies examine potential impacts on sediment transport, fish passage, and habitat continuity. While hard structures provide precise control over the flow and sediment dynamics, they can create unnatural flow conditions that require additional modifications to facilitate fish passage.



Figure 3-1. Hard structures (retaining walls, debris walls, grouted rock)

Source: Santa Barbara County Flood Control District 2024



Figure 3-2. Minimal hard structures (open outlet with debris racks).

Source: Google Street View 2024

3.2 Retention

Retention structures such as slots, grill-type racks, and debris walls aim to trap rock and large debris carried by debris flows and floodwaters. The goal of retention in a debris basin is to capture rock material and debris while allowing water to flow thorough, reducing downstream impacts. Retention structures typically use obstruction to block debris with openings sized smaller than the rocks and logs to be captured. It is important to balance retention and sediment transport to prevent sediment starvation from occurring. The cost of desilting can become larger than anticipated and maintenance challenges often arise from sediment build-up in the basin when retention and sediment transport are not balanced properly. Retention structures should ideally be designed to allow finer sediment to pass during routine events, while larger debris is trapped during high-flow or debris flow events. This helps the basin manage its own sediment supply and reduces the cost of routine maintenance operations.

3.3 Outlet Structures

Outlet structures are essential for regulating the flow of water and sediment through the debris basin. A more restrictive outlet structure will increase flow depth and reduce velocity promoting stronger deposition while a less restrictive outlet structure would create less backwater promoting weaker deposition. Due to the flashy nature of burned watersheds, large surges in flow and debris can occur. Blockages upstream can also spontaneously release large quantities of material. Outlet structures can help detain these surges and meter the outflow. The dimensions of the outlet opening is specific to the hydrology and hydraulics of the project. The opening should be sized considering sediment transport and debris capture needs. The outlet should not be overtopped by the post-burn design storm.

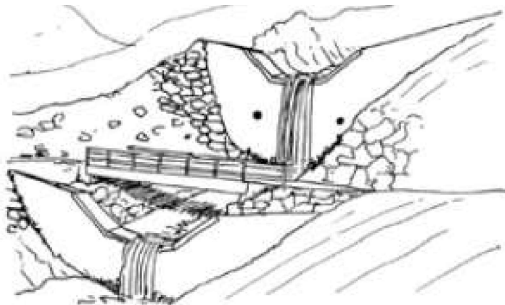


Figure 3-3. Check-Dam.

Source: Bergmeister 2012

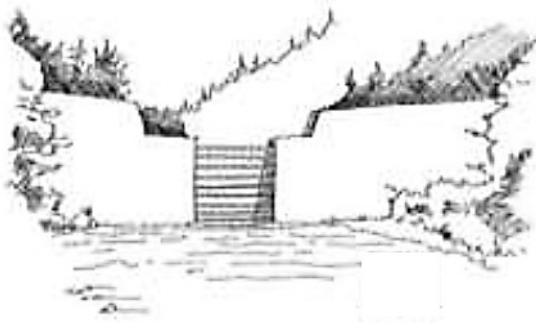


Figure 3-4. Open Check-Dam.

Source: Bergmeister 2012

Types of structures include open outlets, intakes/pipes, spillways, check- and open check-dams. Intakes and pipes are typically worse at restoring natural sediment transport than the other available options and should be avoided. Open outlets are less likely to clog and provide total capture during debris flow events as opposed to check-dams with slot or grille-type openings. As such, the goal of the debris basin and the basin capacity will control what type of outlet structure is selected. If full capture of debris and sediment during post-burn debris flow events is required to sufficiently protect downstream communities, then a check dam structure can be used to pass smaller sediments during normal conditions and provide full capture during debris flow conditions. These types of basins will fill quickly in the event of a debris flow and will require greater capacity than an open outlet. If only capture of large debris and rock is required during post-burn debris flow events, then an open outlet structure can be used to pass smaller sediments during normal conditions and regulate the size of debris and rock leaving the basin during debris flow conditions. Example renderings of various outlet structure types are provided through Figure 3-5.

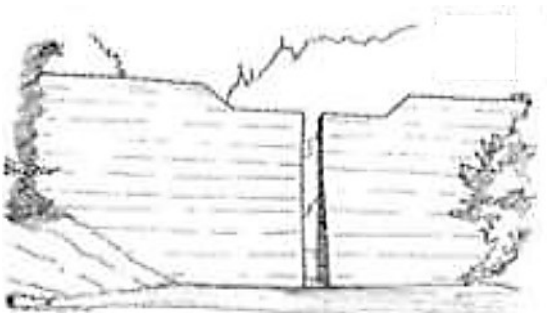


Figure 3-5. Open Outlet.

Source: Bergmeister 2012

3.4 Debris Flow Breakers

Debris flow breakers are structures designed to break the front of a debris flow, reducing its energy and allowing capture of larger materials earlier in the basin. These structures are often useful for steep channel applications where reducing velocity enough for deposition is difficult. Debris flow breakers are typically open check dams with multiple fins or slits designed to allow water and smaller sediment to pass while trapping boulders and large debris. Generally, they have an inclined fin design which promotes self-cleaning and allows bedload sediment to continue through the basin during regular flow conditions, reducing the need for frequent maintenance. The spacing between the slits or fins should be designed to trap the targeted size of rock and debris without causing a complete blockage early in the basin. They are best located in steeper sections or earlier in the basin to break flow before it reaches structures that could sustain impact damage. A debris flow breaker rendering is provided below.



Figure 3-6. Debris Flow Breaker.

Source: Bergmeister 2012

3.5 Large Woody Traps

Large woody debris traps are specifically designed to capture logs, branches, and other large woody materials that can clog channels, damage infrastructure, or exacerbate flooding risks. Debris racks such as piles or grates/grilles, vertical or inclined, can be used to trap wood without fully obstructing the flow within the debris basin.

The most common form of large woody debris trap is the rack. Debris racks are structural elements designed to capture large debris such as rocks, boulders, logs, and branches before they reach critical areas, like the outlet structure or downstream infrastructure. These racks prevent blockages, clogging, and damage to critical components of a debris basin, allowing water and smaller sediment to flow through while holding back large, potentially destructive debris. Debris racks also help regulate water flow by ensuring that only water and fine sediment pass through, reducing the risk of downstream flooding caused by sudden releases of large debris. This is particularly important in urbanized areas or regions with critical infrastructure downstream.

Properly designed woody traps prevent jamming, which can cause water to back up and overflow the outlet, leading to greater downstream hazards. The spacing of debris rack elements should be optimized based on the expected size of debris and the flow conditions. Too narrow of a spacing can cause clogging with smaller materials, while too wide of a spacing may allow damaging debris to pass. The angle of the bars/piles may also be slanted to improve self-cleaning functionality and promote detention of LWD as opposed to retention, allowing debris to be slowly washed away during high flows.

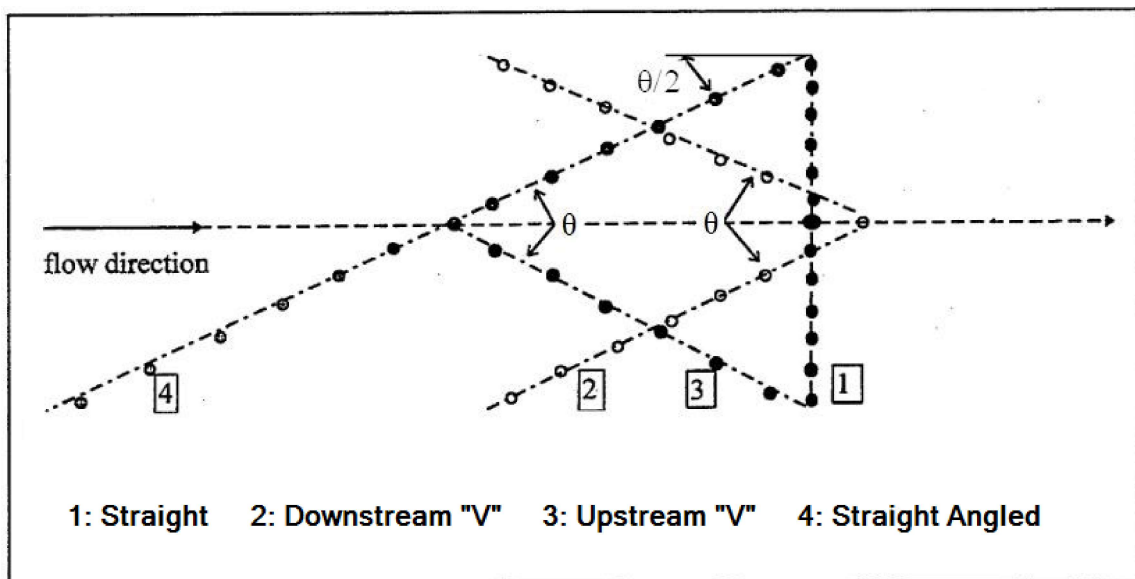


Figure 3-7. Orientation types for woody traps.

Source: USACE 1997

Trapping capacity is proportional to basin area due to the floating nature of LWD. To maximize trapping capacity and reduce risk of jamming, it is often best to provide large woody traps at the outlet structure and mid-basin. Orientation of the rack has a large impact on the trapping efficiency of a debris rack. Studies on the subject have concluded that a downstream pointing "V" has the best debris retention capacity and the least backwater effect when filled with debris. A straight configuration can cause debris to be pushed up and over the barrier and is more likely to clog. An upstream pointing "V" creates more backwater and deflects more debris than a downstream "V." A straight configuration angled to the direction of flow has a lower probability of clogging and debris overtopping, but also tends to deflect debris. A mix of these orientations can be used to both deflect debris into the basin and capture debris before the outlet. A comprehensive analysis and discussion of the different orientations is provided in *Debris Control at hydraulic Structures in Selected Areas of the United States and Europe* (USACE 1997).

3.6 Channel Design

Channels should be designed to allow routine events to transport sediment downstream naturally, maintaining the ecological and geomorphological continuity of the stream, while only larger events trigger sediment and debris detention/retention mechanisms. The channel should prevent flow spreading during normal operation and guide flows toward the outlet. The channel should be self-cleaning so that it does not require excessive maintenance. There are many channel types such as rock ramps, chutes and pools, step-pools, cascade-pool, and roughened. The fish passage guidance provides information on design and implementation.

Rock ramps are continuous, roughened channels constructed with large, random rock placement to add hydraulic roughness. These ramps create varied flow environments and mimic plane-bed channels, lacking structured bedforms like pools. They are suitable for slopes under 4% and elevation changes of 5 feet or less. Rock ramps generally support species that swim rather than leap, making them ideal for fish without leaping abilities.



Figure 3-8. Rock ramp / roughened channel.

Source: Santa Barbara County Flood Control District 2024

Chutes and pools dissipate energy, reduce water velocities, and provide resting spots for fish. The chutes are constructed with rock bands and are generally suitable for slopes around 4%, with pool depths designed to maintain sufficient water depth at both high and low flows. The combination allows fish to move upstream without encountering exhaustion barriers.

Common in steeper, high-energy environments, step-pool channels consist of a series of boulder or cobble steps that separate pools. Each step creates a small waterfall, with water plunging into pools that serve as resting areas and help dissipate energy. Step-pool channels are effective on slopes of 3-5%, with the steps designed to remain stable at high flows to prevent the channel from scouring or eroding. These channels simulate natural features found in mountainous streams.



Figure 3-9. Step-pool/chute and pool channel.

Source: Santa Barbara County Flood Control District 2024

For steeper channels, cascade designs include sequences of large rocks or keystone structures to create turbulent, fast-flowing sections (cascades) that alternate with small pools. Each cascade sequence dissipates significant energy, while the pools serve as holding habitats during high flows. Cascade channels are suited for slopes greater than 6% and require careful rock sizing to remain stable under high-velocity flows.

Roughened channels, often used in confined spaces or where steeper slopes are necessary, are designed with immobile frameworks of large rocks mixed with smaller sediment to provide hydraulic diversity. These channels are adaptable to various slopes and serve multiple purposes, such as passage for smaller, weaker swimmers and profile control. Roughened channels maintain fish passage conditions over a broad flow range and are commonly used in culverts or confined stream sections.

4 HYDROLOGIC AND HYDRAULIC MODELING OF DEBRIS BASINS

4.1 Hydrologic Impacts of Sediment Loading

The main difference between pre- and post-burn hydrology when working with the NRCS Curve number Method is an adjustment to the curve number based on burn severity. The discharge ratio is also adjusted to simulate bulking before importing the hydrographs to hydraulic modeling software. Some hydraulic models allow the volumetric concentration and bulking to be accounted for after post-burn hydrology has been developed. However, the burn severity of different land use types will still guide curve number estimation when analyzing hydrology separate from bulking. A comparison of the methods and parameters used to account for sediment bulking hydrologically and hydraulically are provided in the following table. Double accounting for bulking should be avoided. The hydrologic and hydraulic parameters in red should not be used in conjunction with each other.

Table 4-1. Comparison of Hydrologic and Hydraulic Bulking Methods

Hydrologic Bulking	Parameters in Common	Hydraulic Bulking
Adjust Discharge Ratio	NOAA Atlas 14 Rainfall NRCS Curve Number Post-Burn CN	Select Non-Newtonian Method & Set Parameters Set Volumetric Concentration Set Bulking Method Set Geotechnical Model

With low burn severity, vegetation and root structures are only partially destroyed, meaning the stabilizing effect on the soil remains partially intact.

High burn severity causes the formation of a water-repellent layer (hydrophobic layer) in the upper soil horizon. This layer is formed due to the volatilization of organic compounds from vegetation, which then condense at cooler subsurface depths. The result is a significant decrease in soil permeability and infiltration rates, leading to higher surface runoff, and causing a high potential for post-burn slope failure.

Moderate burn severity lies between high and low burn severity in terms of its impacts on vegetation, soil properties, and subsequent debris flow potential. It represents areas where some of the vegetative cover and soil structure are affected, but not to the same extent as high-severity burns. There can be a partial formation of hydrophobic layers in the soil. These water-repellent layers tend to be less continuous or less severe than in high-severity burn areas.

The best source for burn severity data are the Burned Area Emergency Response (BAER) Burned Area Reflectance Classification (BARC) Soil Burn Severity (SBS) maps which are available on the USGS website (USGS 2024). The pre-burn land cover conditions can be used to inform terrain roughness and curve number for flows in the watershed. For post-burn conditions, the land cover should be modified based on the BARC SBS maps and assigned a higher curve number than pre-burn conditions. The best source for land cover data is the National Land Cover Database (NLCD) available through the USGS website (USGS 2024).

There are several studies which discuss the selection of curve number and bulking factor based on burn severity and watershed conditions. A few include the *Santa Barbara Flood Recovery Mapping Reports* (STARR 2018a and 2018b) and the *Sediment/Debris Bulking Factors and Post-Fire Hydrology for Ventura County Report* (WEST Consultants 2011).

4.2 Hydraulic Modeling

4.2.1 One-Dimensional vs. Two-Dimensional Modeling

In the context of debris basin design and analysis, 1D and 2D modeling are used to simulate water and debris flow dynamics, sediment transport, and other critical factors. While both types of models have their uses, 1D modeling is often considered inferior for complex situations, particularly those involving non-Newtonian flows (like debris flows), sediment transport, or lateral components of momentum (e.g., expansion of debris into a basin).

4.2.1.1 1D Modeling

1D modeling resolves the hydraulic characteristics of a single line of flow along a channel or watercourse, with variations in depth and velocity accounted for in only two directions, upstream and downstream. Any flow into overbanks will not have lateral components for velocity or momentum and would be purely a product of change in depth. Sediment transport, particularly in cases involving large particles or debris, is heavily influenced by lateral variations in velocity and flow depth, which 1D models cannot effectively capture. Additionally, the flow is treated as uniform across a section which is not detailed enough to accurately determine the difference between transportable particle sizes in channel versus in the basin. 1D models are also insufficient for representation of non-Newtonian behavior where the viscosity of the flow changes with applied stress. They do not account for multi-directional stress and velocities which occur within the debris basin. This also renders them insufficient to predict scour and deposition within the basin.

4.2.1.2 2D Modeling

2D modeling resolves flow across both the x (longitudinal) and y (lateral) directions, allowing for detailed analysis of variations in flow depth, velocity, and sediment transport across a plane. In 2D models, the reaches are divided into a grid, with water and debris flow characteristics simulated in each cell. This allows the model to capture the effects of water flowing around obstacles (e.g., boulders, trees) or across uneven terrain, which is

critical in accurately predicting flow paths, debris movement, the effectiveness of large woody debris capture devices, and the performance of the outlet structure.

2D models provide a more accurate representation of sediment transport because they can simulate how sediments move both longitudinally and laterally. This allows for a more precise prediction of sediment deposition, scour, and transport patterns across the entire basin, which is critical for long-term capacity management. 2D models are better suited for simulating non-Newtonian flows, like debris flows, where the flow characteristics change based on local stress, viscosity, and material concentration. By capturing shear forces and viscosity changes across multiple dimensions, 2D models can more accurately represent the movement of debris-laden flows.

In a debris basin, flow velocities and depths can vary dramatically across the basin floor and along the basin's perimeter. 2D models account for these variations and provide a more realistic prediction of localized flooding, velocity gradients, and the potential for erosion or sediment accumulation in different parts of the basin.

4.2.1.3 Fish Passage

In the case of projects which include fish passage and hydraulic design, any NLF or channel with the same function should be modeled to contain the fish passage flows while provide hydraulics adequate for the migratory species with protective freeboard. There are typically separate low-flow and high flow design requirements for adult and juvenile fish passage. Refer to the fish passage guidance documents for design criteria.

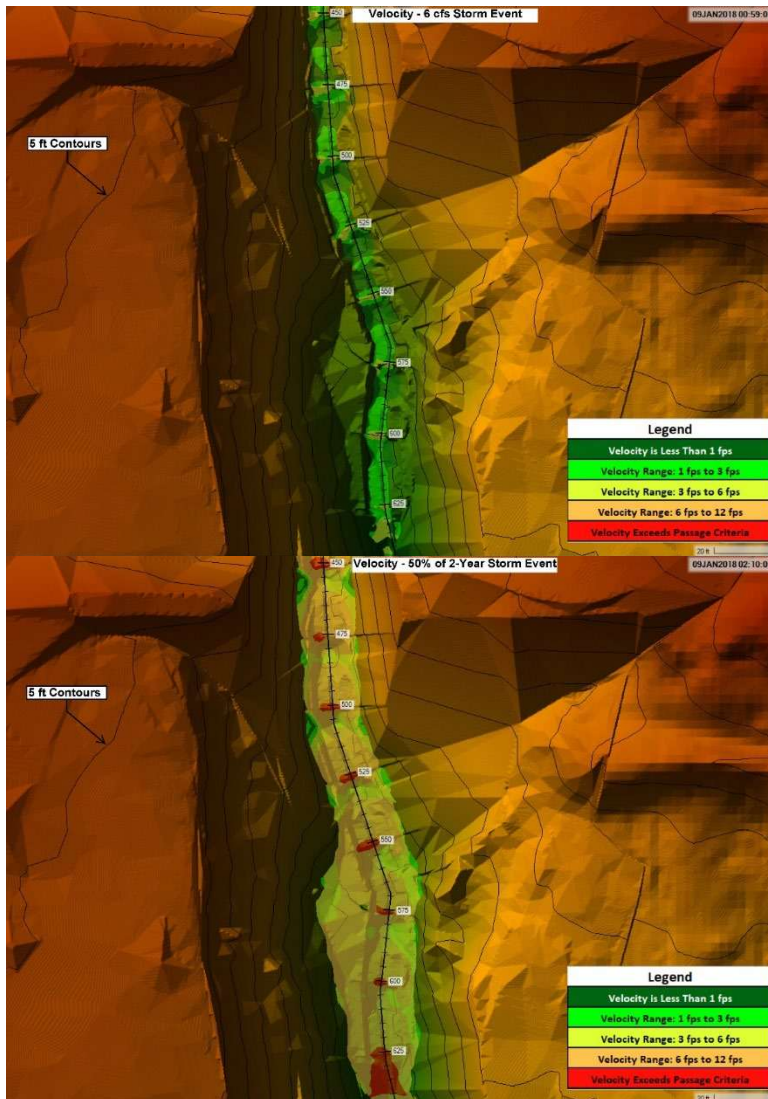


Figure 4-1. Low- and high-flow fish passage modeling (velocity example).

Source: HDR 2023

4.3 Sediment Transport Modeling

The pre-burn hydrology can be modified from within the hydraulic model for post-burn conditions. If this approach is selected, post-burn hydrologic modeling would still be required. The pebble counts and soil testing performed during the geotechnical analysis also provides parameters that are helpful in calibrating non-Newtonian incipient motion and non-

Newtonian sediment transport models. Soil gradation and porosity help inform max volumetric concentration which is directly related to bulking factor. The soil gradation and pebble counts help inform representative grain size and gradations to be modeled for transport. Flows often go non-Newtonian with a debris volumetric concentration of 60% which is equivalent to a bulking factor of 2.5. To appropriately capture how a debris flow behaves, the fluid volume should be dynamically bulked between the max and min volumetric concentration while accounting for dynamic viscosity to simulate the dilatancy of the flow. The analysis should consider hyper-concentrated, mudflow, grain flow, or debris flow types based on historic debris flow information, the geotechnical analysis, and survey.

The geotechnical tests can also provide estimates of internal friction angle which helps inform the yield stress which is important for defining the internal strength of the debris flow and its resistance to motion under stress. Debris flows behave as a solid when stress is less than the yield strength.

Debris flows can produce substantial shear in scour zones and significant aggradation in deposition zones. Coupling the non-Newtonian physics with a sediment transport model will allow designers to visualize the effects of debris flows on the terrain. These models are incredibly difficult to calibrate and stabilize. Most modeling software capable of 2D sediment transport have options for modifying cell shape. When modeling in 2D, it is best to use as many cell faces as possible to help stabilize the model. Behavior of a debris flow can be difficult to predict as the content of the debris in the flow will change between events. These transport models are generally more helpful in determining impacts of scour and deposition on flooding downstream than predicting sediment loads.

A strong sediment transport design will restore and/or maintain natural mobilization of streambed materials through the project reach. This will reduce maintenance while providing stable habitat in the creeks and nourishment to beaches downstream.

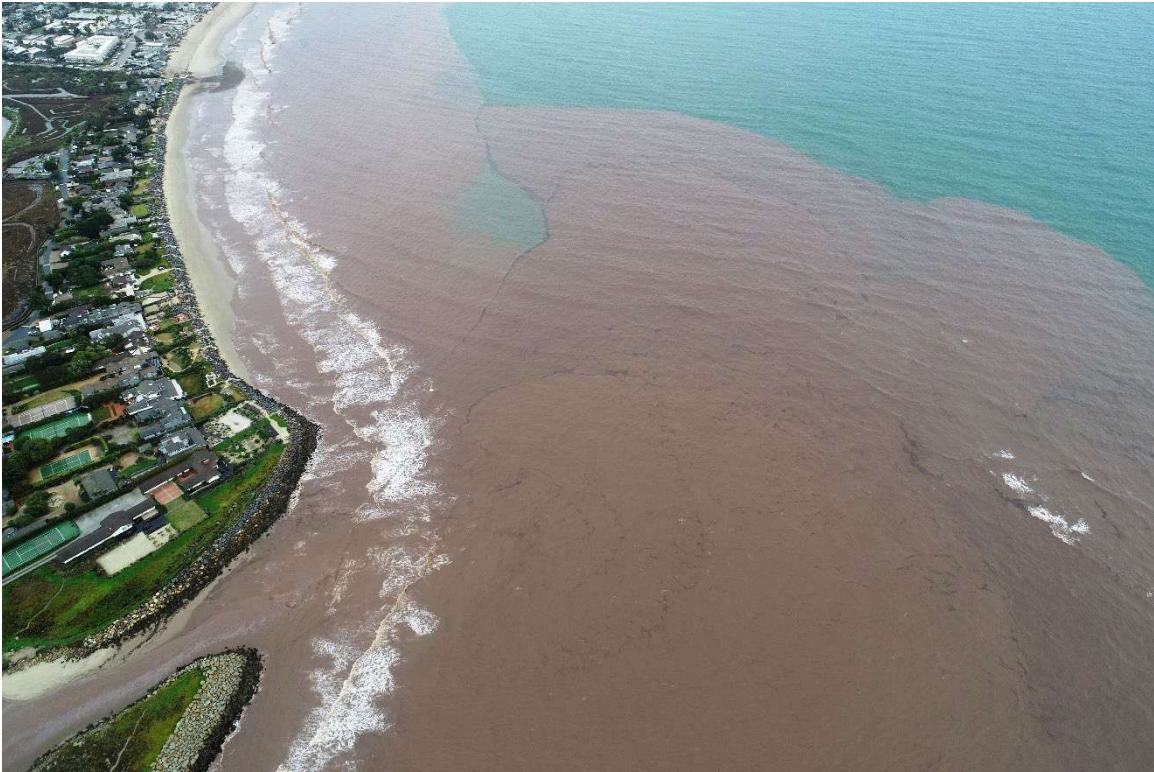


Figure 4-2. Sediment Transport to Downstream Beaches

Source: Santa Barbara County Flood Control District 2019

The types of hydraulic and sediment transport analyses to be performed should be decided prior to the geotechnical analysis to ensure appropriate information is collected for design.

5 CASE STUDY OF COLD SPRINGS, GOBERNADOR, MARIE YGNACIO, AND ROMERO DEBRIS BASINS

The following case studies provide a summary of the design challenges, construction lessons, and performance of four debris basin modification projects executed between the years of 2008 and 2024. The four sites have many challenges in common.

Post-modification, the constructed channels at the outlet opening and the remaining downstream channels tend to settle and lose sediment during large storm flows. Natural streambed material gradations may need to be upsized to resist scour in the initial years of operation while the reach finds equilibrium. The distribution can mimic the natural streambed by upsizing the entire particle distribution of the reference reach. It is important to appropriately size and lock-in boulder features while providing adequate embedment and point-to-point contact between rocks or proposed rock features will wash away during large storms.

The variability of material sizes and complex placement practices required to form stable and nature-like reaches makes it difficult to achieve accuracy with debris basin construction. It is important to monitor construction activities and check elevations throughout the construction process to achieve adequate rock placement and grade.

Forming fish habitat within the basin can impede maintenance. When fish passage is a concern, the modifications should be envisioned as a migratory corridor, pass-through habitat for fish species, preventing fish species from over-summering in the basin. The site should be designed to maintain fish transit through the basin. The objective is not to create high quality fish habitat within the site.

Cold Springs Debris Basin Case Study

General Information

- Debris basin modification project
- Original basin constructed in 1964, grouted rock embankment with low flow pipe (48-in RCP)
- Significant damage sustained in 2018
- Located along Cold Springs Creek
- Salmonid reach
- Watershed: 3.7 square miles
- 100-yr pre-burn flow rate: 3,910 cfs
- Bid for modification was \$2.86 million

Design Challenges

- 18-ft elevation drop due to sediment starvation downstream of pipe outfall
- Steep upstream slopes reaching 10%
- High flow-rates with steep slopes damage non-protected project elements
- Steep grade exceeds the slopes described in the fish passage guidance
- Multiple design iterations required



Figure 5-3. Post-Modification Cold Springs Debris Basin Downstream Improvements, looking upstream (Dec 2024)

Construction Lessons

- Rock-by-rock placement requires real-time topo survey equipment for spot checks
- Close coordination required between operator, field staff, and surveyor for proper rock placement
- Provide an example of rock placement that is to scale

Additional Lessons

- Careful evaluation of rock size and elevation is crucial to avoid forming a jump or scour in the riffles between pools



Figure 5-1. Original Cold Springs Debris Basin Embankment, looking upstream (May 2024)

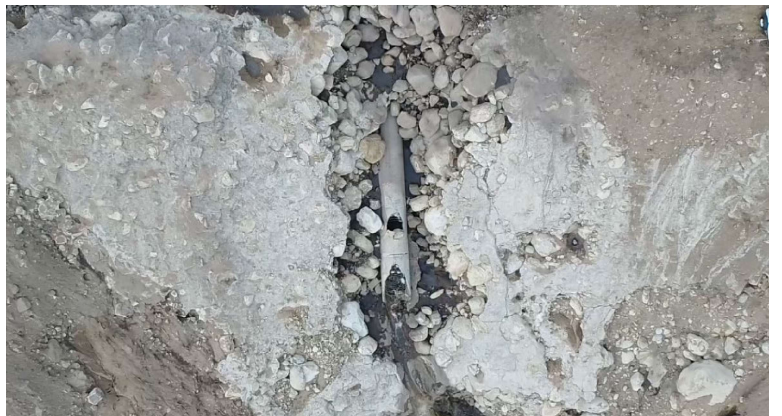


Figure 5-2. Original Cold Springs Debris Basin Post-2018 Storm Damage



Figure 5-4. Post-Modification Cold Springs Debris Basin & Pilot Channel, looking upstream (Dec 2024)

Cold Springs Debris Basin Case Study

concrete pipe (RCP) outfall. It was installed in 1964 by the USACE in response to the 1964 Coyote Fire which burned roughly 67,000 acres of mountainside.

The low flow pipe through the embankment had a capacity of approximately 200 cfs, constricting most storm flows or clogging completely, leading to the debris basin filling with sediment even during minor storm events. During the debris flow event on January 9, 2018 after the Thomas Fire, the low flow pipe was once again clogged, flows overtopped the basin, and the debris flow blew out the embankment.

Grant funding was secured by the Santa Barbara County Flood Control District for the modification of the basin in 2018 with a goal of reinforcing the basin, improving basin performance during floods and debris flow events, improving sediment transport through the basin, and removing the embankment as a fish passage barrier.

Several iterations of designs and comments with NMFS and CDFW were required to alleviate concerns of sediment transport and fish passage for a step-pool design. Regulatory agencies were concerned the pilot channel would periodically fill in with sediment during large storms or be disturbed by sediment removal operations and that the basin would prevent natural replacement of large bed material to the riffles downstream. There was also concern sediment deposition would cause the jump pools to become too small/shallow or that the riffle crests would erode increasing jump height. Sediment transport, incipient motion, and scour analyses were required to alleviate these fears in addition to the hydraulic analysis of fish passage criteria. The analyses needed to be balanced such that:

- The pilot channel is self-cleaning while maintaining fish passage
- The outlet structure creates backwater during large storms to induce deposition while providing smaller fish passage events clearance from structural elements
- The outlet and pilot channel maintain a minimum particle transport size for replenishment of riffle material

- The pools self-scour without too high of an energy dissipation factor (EDF) or non-passable hydraulics

After several iterations, a step pool design was established that could transport similar rock sizes of 30-inches in diameter or smaller, both through the basin and the downstream improvements, maintaining stable sediment transport through the project reach while providing fish passage.

For approximately 120 ft downstream of the outlet, grouted rock side slopes lead into sub-surface grouted rock cutoff walls to protect this segment of step pools from scour and stabilize the steep banks. Protrusion of the rock within the cutoff walls into the center channel bed material was essential to provide an interlocking system of boulders for additional stability within the reach during storm flows. Large rocks and a grouted rock toe at the downstream footing of the outlet structure was also used to mitigate potential scour downstream of the outlet structure. Static structures such as grouted rock weirs with low flow notches to reinforce the riffle crests were also required to alleviate the fear of erosion of downstream fish passage features and potentially increase jump heights. Due to design complexity, it was crucial that design team staff with fish passage knowledge were onsite directing all grouted rock placement with use of laser levels tied to survey stakes to ensure proper elevations, weir complexity and roughness was obtained to meet design goals. The grouted rock weirs were locked into the cut-off walls. Large woody debris (LWD) was installed in the pilot channel to increase habitat heterogeneity. Habitat boulders, engineered streambed material (ESM), and boulder clusters were provided to further improve habitat heterogeneity and channel roughness

Construction of the basin modification occurred in the Summer and Fall of 2024 over 120 working days. At the time of this case study, the modified basin has yet to experience a large storm event.

Gobernador Debris Basin Case Study

General Information

- Debris basin modification project
- Original basin constructed in 1971, grouted rock embankment with low flow pipe (48-in RCP)
- Located along Gobernador Creek
- Salmonid reach
- Watershed: 13 square miles
- 100-yr pre-burn flow rate: 17,445 cfs
- Bid for modification was \$900K

Design Challenges

- High flow-rates with steep slopes damage non-protected project elements
- Limited guidance prior to 2011
- Steep grade exceeds the slopes described in the fish passage guidance
- Downstream project limit constrains jump height
- Creek has a 90° bend at the basin outlet



Figure 5-5. Modified Gobernador Debris Basin, looking downstream (Aug 2024)



Figure 5-7. Post-Modification Gobernador Debris Basin, looking into basin (March 2023)

Storm Performance/ Maintenance Impacts

- The modified basin has been operating since 2008 providing substantial debris and rock retention
- Smaller sediments continued downstream
- The concrete apron downstream scoured and required modification



Figure 5-6. Original Gobernador Debris Basin Embankment, looking upstream (May 2008)

Construction Lessons

- An access lane should be included to maintain the channel downstream of the outlet
- Forcing features such as large boulders and rock weirs should be properly interlocked into cutoff-walls to prevent mobilization
- A forcing feature should be provided to stabilize the downstream grade
- Cutoff walls at toe should be roughened and not smooth concrete as streambed material will slide off when flow is present leading to bed scour
- Pilot channel sizing must be taken into consideration based on the desired material size to be transported during storm flows and also to meet fish passage requirements

Gobernador Debris Basin Case Study

The original Gobernador Debris Basin and embankment was a 23-foot-high grouted rock embankment with a 48-inch low flow reinforced concrete pipe (RCP) outfall. It was installed in 1971 by the USACE in response to the Romero Fire burned a large percentage of the watershed and others.

The low flow pipe through the embankment had insufficient capacity leading to excessive backwatering and the debris basin filling with sediment even during minor storm events. Grant funding was secured by the Santa Barbara County Flood Control District for the modification of the basin in 2008 over 70 working days with a goal of reinforcing the basin, improving basin performance during floods and debris flow events, improving sediment transport through the basin, and removing the embankment as a fish passage barrier.

At the time of project initiation, regulatory guidance on fish passage was limited. The guidance on debris basin modification was also limited. There was a 14-page document on salmonid passage from the National Marine Fisheries Service (NMFS) dated 2001, a third edition California Salmonid Stream Habitat Restoration manual from the California Department of Fish and Wildlife (CDFW) dated 1998, and a 16-page document on salmonid habitat restoration from CDFW dated 2002. The existing channel slope downstream of the embankment was greater than 6%. Fish passage facility design along such steep slopes were considered experimental by the regulatory agencies. Extending the downstream project limits to try and reduce the slope would make it infeasible to catch grade. The overall channel slope was reduced to 5% by grading down at the outlet and providing jumps. The reduction in grade made upstream passage for adult salmonid spawning possible but could not support juvenile migration in the same direction. Resting pools were provided for the adult fish migrating upstream and the juvenile fish migrating downstream. Although this condition was not ideal, it was a large improvement over the complete barrier to fish passage presented by the embankment.

An incipient motion analysis was performed to describe sediment mobilization in the modified basin and assist in the evaluation of long-term sediment functionality. The analysis found that any coarse gravel that entered the basin would remain, while finer gravels would mobilize out of the basin during large storms. The mobilization of only small sediments through the outlet was a function of basin slope and the 90-degree bend in Gobernador Creek at the basin outlet, both of which induced greater deposition upstream. This allows spawning gravels to continue downstream and finer materials to nourish downstream beaches. After modification in 2008 desilting was not required until 2017 in order to prepare for potential winter storms in response to the Thomas Fire which burned nearly the entire watershed above. It has since been desilted in 2018 after a debris flow and in 2023 after record rainfall and the debris walls were completely filled with woody debris and the basin filled with material. In 2023 the pilot channel was deepened during desilting efforts in order to allow smaller material to better pass through the basin during smaller storm flow events.

The site tends to lose sediment/boulders during large storms. The boulders placed to form resting pools also mobilized during large storms due to inadequate embedment, point-to-point contact, and sliding over smooth concrete cutoff walls. The channel bed between the embedded boulder structures was composed of native streambed material of a range of sizes that can mobilize. Since construction, the downstream channel bed has lowered by a few feet exposing the concrete apron downstream of the outlet due to deficient sediment transport through the basin. A concrete check structure was designed with a couple boulders protruding out to act as grade control. Scour holes began forming downstream of the check structure becoming a maintenance issue. It was determined maintenance access to the downstream improvements was necessary for sediment/boulder replacement and other maintenance activities.

Maria Ygnacio Debris Basin Case Study

General Information

- Debris basin modification project
- Original basin constructed in 1990, grouted rock embankment with low flow pipe (54-in RCP)
- Along Main Branch Maria Ygnacio Creek
- Salmonid reach
- Watershed: 4.0 square miles
- 100-yr pre-burn flow rate: 3,400 cfs
- Bid for modification was \$400k

Design Challenges

- Home to diverse wildlife: red legged frog, coast range newts, southwestern pond turtles, snakes, steelhead/trout, nesting birds, etc.
- Available on-site streambed material of suitable size
- Narrow floodplain
- Tight work-window



Figure 5-8. Original Main Branch Maria Ygnacio Debris Basin Inlet Grouted Rock Check Structure, looking upstream (April 10, 2019)



Figure 5-9. Original Main Branch Maria Ygnacio Basin Embankment, looking upstream (April 10, 2019)



Figure 5-10. Modified Main Branch Maria Ygnacio Debris Basin, looking upstream (Dec 13, 2019)

Storm Performance / Maintenance Impacts

- Regularly captures debris at rack as watershed recovers, requiring maintenance for removal
- Passes mostly 12-inch rock or smaller during large storms while gravels still transport during small storms
- Anadromous fish and other wildlife have returned to the site successfully

Construction Lessons

- LWD must be angled upstream with appropriately sized rock ballast for stability
- Upsize natural streambed gradation with sufficient quantities of rock to combat settling and erosion
- Anticipate maintenance for good long-term fish passage and sediment performance



Figure 5-11. Modified Main Branch Maria Ygnacio Debris Basin w/ Rack Full of Debris, looking upstream (January 17 2023)

Maria Ygnacio Debris Basin Case Study

The original Main Branch Maria Ygnacio Creek Debris Basin and embankment was a 18-foot-high grouted rock embankment with a 54-inch low flow reinforced concrete pipe (RCP) outfall. It was installed in 1990 by the United States Department of Agriculture Soil Conservation Service and the Santa Barbara County Flood Control District in response to the 1990 Painted Cave Fire.

Grant funding was secured by the Santa Barbara County Flood Control District for the modification of the basin in 2019 with a goal of improving basin performance during floods and debris flow events, improving sediment transport through the basin, and removing the fish passage barriers. The grouted rock embankment and grouted rock grade control inlet structure were removed and the creek restored through the project area. The design included parameters to install a temporary debris rack in response to fire in the watershed that are removed after 5-years when watersheds have had a chance to recover. The Cave Fire broke out in the watershed soon after project completion and a debris rack was installed in December 2019.

A stream simulation design was used for the project which used an upstream natural reference reach with similar slope to determine streambed material sizing, channel dimensions, and forcing features to design the project. The basis of this design approach is to create a natural channel through the project reach that will function seamlessly with the natural creek.

The basin acts as a large flood plain allowing larger material to drop out during storm flows which maintains basin functionality and also creates additional habitat complexity. A stream simulation design can also be much cheaper as there was no concrete outlet structure that could add to design, construction, and maintenance costs. One of the most critical components of stream simulation design

is the correct size classes and quantities of the streambed material used to construct the project channel, as this is the basis of the design and the entire creek working naturally when transporting streambed material during storm flows. If the streambed material is not correct it can lead to erosion that may require corrective actions if unnatural jumps form creating fish passage impediments.

Quantities and sizes of streambed material within the grouted basin cap were unknown and smaller than anticipated once excavation began. This led to less channel roughness than desired in some areas and was monitored closely. During initial smaller storm events uniform clay beds were exposed in some areas, but this did not result in any fish passage barriers or trigger corrective measures. Steelhead trout were observed throughout the project site during each site visit after project completion. This issue was rectified completely with large storm flows in January 2023 when large amounts of streambed material were mobilized upstream and deposited throughout the site, completely transforming the project reach and adding vast habitat complexity.

The basin saw near historic rainfall amounts with peak flows of 1,320 cfs at the Maria Ygnacio gauge on January 9, 2023. The debris rack trapped and filled with a large amount of woody debris which created an artificial grade control structure and caused streambed material to fill the channel upstream to the top of debris rack elevation. Stream flow was diverted around the rack and both banks were partially eroded. Volitional passage was maintained around the structure but may have been difficult during low flows due to jump heights. Maintenance restored the site in approximately 2 hours once flows had receded enough to ensure safe access.

Romero Creek Debris Basin Case Study

General Information

- Debris basin modification project
- Original basin constructed in 1972, grouted rock embankment with low flow pipe (48-in CMP)
- Located along Romero Creek
- Salmonid reach
- Watershed: 2.0 square miles
- 100-yr pre-burn flow rate: 1,190 cfs
- Bid for modification was \$2.18 million

Design Challenges

- 9-ft elevation drop due to scour at pipe outfall
- Steep upstream slopes reaching 12%
- 22-inch gas line upstream of basin
- Split flow entering the basin causing damage to maintenance access
- Fish passage design iterations from step-pool to roughened ramp



Figure 5-12. Original Romero Debris Basin Embankment, looking upstream



Figure 5-15. Romero Debris Basin during Jan. 2023 flood event



Figure 5-13. Post-Modification Romero Debris Basin, looking upstream

Construction Lessons

- Constructed in Summer 2022 over 120 working days
- For large rocks or bedrock at wall footings, high density Styrofoam can be used in place of Clase II AB.
- Given existing terrain, minimizing wall height resulted in overly steep maintenance ramp.

Storm Performance / Maintenance Impacts

- January 2023 rainfall totals topped 17 inches in some locations
- Basin maintained a high sediment transport with larger materials settling in the basin.
- No regular maintenance of clearing the basin has been required as of November 2024.



Figure 5-14. Romero Debris Basin, February 2024

Romero Creek Debris Basin Case Study

The original Romero Creek Debris Basin and embankment was a 20-foot-high grouted rock embankment with a 48-inch low flow corrugated metal pipe (CMP) outfall. It was installed in 1972 by the USACE in response to the 1971 Romero fire.

The low flow pipe through the embankment would regularly constrict moderate to large flows or clog completely, leading to the debris basin filling with sediment even during minor storm events. During the debris flow event on January 9, 2018 after the Thomas Fire, the low flow pipe was once again clogged and the basin completely filled with sediment and flows overtopped the embankment.

Grant funding was secured by the Santa Barbara County Flood Control District for the modification of the basin in 2018 with a goal of improving basin performance during floods and debris flow events, improving sediment transport through the basin, and removing the fish passage barrier. Improvements would mimic the previously modified Gobernador Debris Basin design with a larger opening outlet structure and debris walls.

Several iterations of designs and comments with NMFS and CDFW were required to reach a consensus on the downstream reach design. Originally planned as a grouted step-pool system, a preference for a roughened ramp approach was reached due to the reduction of grout, relatively moderate slope (7 to 8%) downstream of the outlet, and the resulting difficulties in meeting and maintaining fish passage hydraulic criteria of a step-pool design. The roughened ramp approach required additional information on the reference reach including pebble counts, wetted width measurements, and bankfull width measurements. The pebble count data was used to inform the gradation mix of the roughened ramp material and the wetted width and bankfull width data was used to guide the outlet structure opening width.

The grouted rock on the downstream side slopes lead into sub-surface grouted rock cutoff walls to protect this segment of reach from scour. Protrusion of the rock within the cutoff walls into the center channel bed material was essential to provide an interlocking system of boulders that provide additional stability to the reach. Large rocks and a grouted rock toe at the downstream footing of the outlet structure was also used to mitigate potential scour downstream of the outlet structure.

An incipient motion analysis was used to estimate the size of sediment material that would be transported through the basin. Estimates show that sediment material 8-inches or smaller in diameter would move through the shallow sloped basin (2 to 3%) and transport to the downstream reach while larger material would settle within the basin.

Construction of the basin modification occurred in the Summer and Fall of 2022 over 120 working days. Construction was completed in time for a large storm event in January 2023 which saw upwards of 17 inches of rainfall in some portions of the watershed. The basin performed well with larger material accumulating in the basin and smaller material being conveyed downstream. Some large woody debris became lodged in the debris walls which caused some backwater impacts but the other openings within the outlet structure were sufficient to continue conveyance. The outlet structure was never fully blocked and was never overtopped.

After the storm, the pilot channel was re-formed and basin restored in 2 days, which substantially reduced maintenance costs and was an environmental benefit due to the short time of equipment in the creek and remaining material can continue the natural sediment transport process downstream. The unmodified basin would have likely been filled and required substantial desilting and trucking of material offsite. As of the publishing of this manual, no additional clearing of the basin material has been required.

6 POTENTIAL FUNDING SOURCES

After disasters, FEMA can provide funds to local governments for the construction of debris basins to mitigate future risks. FEMA is a source of funding for debris basin projects through the Hazard Mitigation Grant Program (HMGP) and Pre-Disaster Mitigation (PDM) grants. Post-Disaster funding may also be provided by FEMA through the Public Assistance (PA) program for activities such as debris removal. FEMA's Building Resilient Infrastructure and Communities (BRIC) and Flood Mitigation Assistance (FMA) programs may also fund proactive infrastructure projects, such as debris basins, which improve community resilience. Local agencies can apply for BRIC and FMA funding to build or upgrade debris basins, making them more resistant to flood and debris flow hazards. The U.S. Army Corps of Engineers (USACE) and the Natural Resource Conservation Service (NRCS) may provide technical assistance and sometimes funding through partnerships with local agencies.

Federally funded basin projects must comply with the National Environmental Policy Act (NEPA), which requires an environmental review to assess potential impacts on the environment, including wildlife, water quality, and nearby ecosystems. The NEPA process involves preparation of Environmental Impact Statements (EIS) or Environmental Impact Assessments (EIA).

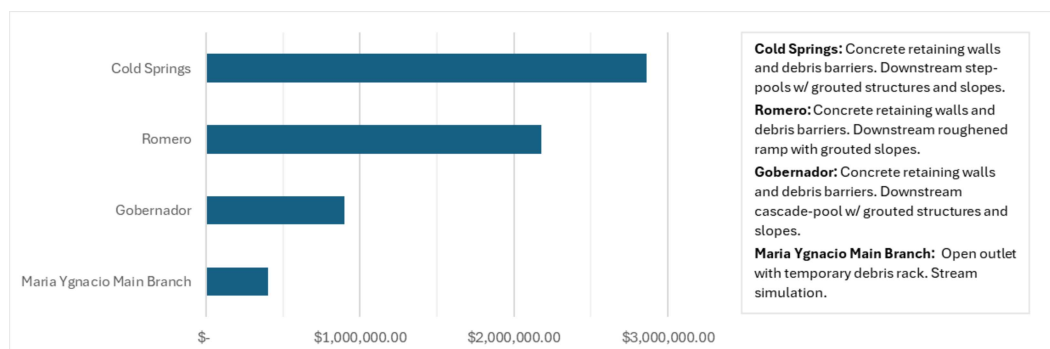


Figure 6-1. Comparison of project cost.

Source: Santa Barbara County Flood Control District 2024

The California Office of Emergency Services (Cal OES) administers FEMA mitigation funds and provides state-level funding for debris basin projects through state mitigation programs. Cal OES acts as an intermediary between federal funding agencies and local governments to ensure the basin projects are aligned with state disaster preparedness goals. Cal OES may provide matching funds or assist local agencies in securing federal grants.

The California Department of Water Resources (DWR) may provide funding for projects aimed at reducing flood risks through grants such as the Flood Maintenance Assistance Program (FMAP) in addition to providing technical guidance on debris management and flood control. A number of California agencies may provide grant funding to enhance fish-passage as well as coastal resilience, both of which can be achieved through debris basin modification projects. Potential state agencies include the California Ocean Protection Council (OPC), State Coastal Conservancy, State Park and the Coastal Commission.

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