Stream Restoration Technical Solutions

Wahikuli and Honokōwai Watersheds, West Maui

Report prepared by the Coral Reef Alliance
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1. INTRODUCTION OF THE PROBLEM

Maui has more impaired waters than any other Hawaiian island. Currently, ninety-two percent of Maui's assessed water bodies suffer from turbidity impairments, and 70 percent of marine water bodies that are regularly tested by the Hawaiʻi Department of Health (DOH) fail federal government nutrient standards. In 2014 and 2015, the DOH issued brown water advisories for Maui spanning 53 days and 69 days, respectively.[1] These events represent significant health threats to humans and marine ecosystems. In addition, they are leading to tangible changes in coral reef health. Over the past two decades, live coral cover has declined an average of 25 percent in West Maui and up to 50 percent in localized areas.[2]

Historical land uses in West Maui have been a major source of land-based pollution that continues to damage coral reef ecosystems to this day. West Maui land was historically utilized for large scale plantation cultivation of pineapple and sugar cane. Over 100 years of intensive farming of this land has left a degraded landscape of eroding dirt roads and fallow agriculture fields which actively continue to transport sediment directly to streams whenever it rains. Intensive farming also led to the introduction of massive inputs of sediment that was pushed or washed into stream gulches. Recent field studies located substantial numbers of these 'legacy sediment' deposits found adjacent to streams.[3] In some locations in the Wahikuli and Honokōwai Watersheds, legacy sediment measures twelve feet thick in terraces along stream banks.[4] Even during relatively low-volume rain events, flowing streams pick up sediment from these deposits, and transport it to the ocean where it increases turbidity in the nearshore environment. High levels of turbidity caused by sediment runoff can reduce corals' access to the sunlight necessary for photosynthesis; settle on corals, thereby smothering them; and act as a delivery mechanism for pollutants like nitrogen, phosphorous, agrichemicals, and pathogens. An excess of nutrients in the ecosystem can lead to algal blooms overtaking coral. Agrichemicals can inhibit corals' metabolic processes, and pathogens can cause outbreaks of coral diseases and death. With the goal to address these significant threats, the Coral Reef Alliance's (CORAL) work in Hawaiʻi focuses on restoring natural stormwater filtration processes within watersheds to prevent land-based sources of pollution from reaching the ocean through streams and groundwater.

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[1] http://emdweb.doh.hawaii.gov/cwb/wqd/viewer/(S(fpbfgyft0cuqlguik005wumd))/Archive.aspx
[2] Coral Reef Assessment and Monitoring Program; Trends in Coral Cover 2012
[3] Preliminary data resulting from USGS field study conducted October/November 2015 (pending publication in 2017)
[4] Field observations from USGS led stream survey conducted November 2015

1.1 Wahikuli-Honokōwai Management Plan

The Wahikuli-Honokōwai Watershed Management Plan[5] recommended a number of management strategies, including stabilizing agricultural access roads, addressing fallow agricultural fields, assessing treated wastewater and reuse, analyzing dam and conveyance structures, providing vegetation management, preventing wildfire, and addressing urban pollution. This *Stream Restoration Technical Solutions* report will focus on a subset of these recommendations that address sediment transport to streams and gulches. This report also further refines solutions contained in the Management Plan and propose new solutions for specific use in West Maui. We provide an overview of each solution, which includes:

- Technical information detailing how a particular solution functions to achieve sediment reduction goals
- Location-specific information outlining why a particular site or type of site is conducive to a solution
- Permitting, maintenance, and budgetary considerations for each solution
- A draft work plan for installing a particular solution
- Metrics and methods for monitoring and evaluating the efficacy of these solutions to reduce pollution

Because this report is focused on uniquely Hawaiian stream and watershed restoration solutions, CORAL will continue to build upon this report as we lead implementation of specific solutions in Wahikuli and Honokōwai Watersheds. It is important to note that the problems found in Wahikuli and Honokōwai Watersheds are by no means confined to these locations, but are evident throughout the state of Hawaiʻi. As CORAL and our partners implement these solutions, we will assess their efficacy at achieving sediment pollution reduction goals, develop detailed implementation plans and budgets, and describe lessons learned that will contribute to adaptive management of pilot projects as well as inform additional restoration efforts across the State.

[5] http://www.westmauir2r.com/watershed-management-plans.html

2. APPROACH

In the West Maui Priority Area, CORAL has launched a project to restore midslope streams to reduce the amount of sediment and nutrients flowing to the ocean. The first step of this project was to design specific restoration solutions to address the pollution problem. In Spring 2016, Ridge to Reefs, a Maryland based restoration nonprofit, convened the West Maui Gulch Sediment Stabilization Roundtable (WMGSSR) under a grant from the National Fish and Wildlife Foundation (NFWF).[6] This two-day workshop identified sites for three vetiver sediment traps to be piloted in the Wahikuli Watershed. These sediment traps were completed in November 2016. The learnings from this workshop and its subsequent vetiver installations highlighted the need for an ongoing group to further identify and pilot a suite of Hawaiʻi-specific restoration solutions and tools that can function successfully within the unique ecosystems and watersheds found in the State. Building upon solutions proposed by the WMGSSR, and at the request of the West Maui Ridge to Reef Initiative (WMR2R) Working Group, CORAL is facilitating a Stream Restoration Knowledge Sharing Group (Knowledge Sharing Group) to identify, pilot, and further refine stream restoration best management practices (BMPs) that are technically feasible, culturally appropriate, and financial sustainable. The Knowledge Sharing Group comprises a wide range of scientists, engineers, land managers, and traditional Hawaiian practitioners, with the goal of creating a pipeline of viable shovel-ready restoration projects starting in West Maui and expanding Statewide.

2.1 Members of the Stream Restoration Knowledge Sharing Group

This group comprises experts from the following organizations, as well as State and Federal agencies:

Commission on Water Resource Management (CWRM) was formed in 1987 and is the governing body for water resources in the state of Hawaiʻi. They support this project through setting up and monitoring stream flow gauges and seeking input from CORAL and stakeholders to set new low flow standards for off-stream use.

Coral Reef Alliance (CORAL) is a U.S.-based nonprofit organization whose mission is to unite communities to save coral reefs. Working with people around the world—from fishermen to government leaders, divers to scientists, Californians to Fijians—CORAL protects our most valuable and threatened ecosystems. CORAL has more than a decade of experience working in the Main Hawaiian Islands on coral reef conservation. Currently, our work focuses on our Clean Water for Reefs Initiative, with an emphasis on preventing land-based sources of pollution from entering streams and groundwater which eventually lead to the ocean. CORAL will lead restoration activities in collaboration with farmers, Hawaiian communities, local nonprofits, private businesses, and the government. CORAL will also collaborate with experts to measure the effectiveness of these approaches and we will share these results and implementation procedures to help inform restoration efforts statewide.

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[6] http://www.ridgetoreefs.org/uploads/1/6/0/3/16037150/west_maui_project_wahikuli_dec_2016.pdf

Ecosystem Restoration LLC is a Maryland-based stream restoration and landscape architecture firm. Ecosystem Restoration provides pro bono advice on restoration projects, and technical support in the form of engineering and design plans drafting and review.

Hawai'i Department of Land and Natural Resources (West Maui Lands Division) (DLNR) provided CORAL with a right of entry document that allows us to conduct restoration activities on State Lands in Wahikuli and Honokōwai Watersheds. We are working with this division to prioritize roads for closure in Wahikuli.

Kāʻanapali Operators Association (KOA) provides management and oversight of Kāʻanapali properties and reviews proposed projects. KOA also represents over 1,000 union workers on Kāʻanapali properties. Kāʻanapali Operators Association would likely review proposed BMPs.

Kupunas (elders) are people with cultural and historic ties to the landscape as long-time residents of the area or through 'kuleana' lands. Kuleana lands are lands that were traditionally utilized or taken care of by a particular Hawaiian family over several generations. Kuleana lands generally were associated with traditional agriculture practices like growing taro (kalo).

Maui Cultural Lands (MCL) is a grassroots land trust organization dedicated to stabilizing, protecting and restoring Hawaiian cultural resources. MCL is already using native species and traditional cultural practices to restore lands. MCL will be intimately involved in the restoration and maintenance activities and will collaborate with CORAL to expand MCL's extensive volunteer base. We will also collaborate to develop restoration templates that honor cultural traditions and effectively restore ecosystem function to the land and streams, which can be used in West Maui watersheds and other locations in Hawaiʻi. Ultimately, these practices will improve water quality and reduce sediment transport to the reefs. MCL's project site at Honokōwai Valley is adjacent to Wahikuli and is ideally suited for supporting the project with equipment mobilization, workforce transport, and site-specific restoration know-how. MCL will also lead the Hawaiian cultural protocols and ensure activities maintain appropriate etiquette and procedures.

There is a strong need for building MCL's restoration capacity in Maui because the dominant land uses are rapidly shifting away from intensive, large-scale agricultural production, leaving behind thousands of acres of severely degraded landscapes. For example, when pineapple production stopped in 2010, 22,000 acres of former pineapple field was allowed to go fallow.[7] In 2016 the government announced that all commercial sugar cane production on Maui would stop by the end of the year. This leaves 36,000 acres of extremely degraded fallow land.[8] Without proper restoration, revitalization, and the local traditional knowledge and technical capacity to accomplish it, these landscapes will continue to be a significant source of land-based pollution and a substantial threat to the reefs surrounding the island.

[7] Derek Paiva Nov 4, 2009, End of an era: Maui Land and Pineapple closing its pineapple operations. Hawaii Magazine
[8] Andrew Gomes, January 6, 2016. Last sugar plantation in Hawaii to close this year. Honolulu Star Advertiser

Natural Resources Conservation Service (NRCS) is a division of the US Department of Agriculture (USDA), NRCS provides technical services related to resource conservation and agriculture to land owners, and financial assistance through cost sharing programs such as the Environmental Quality Incentives Program whose purpose is to help landowners improve their soil, water and related natural resources, including grazing lands, wetlands, stream corridors, and wildlife habitat. NRCS is providing technical support, and working with us to explore land leasing arrangements whereby CORAL or another entity could lease stream corridors in order to be able to qualify for these various programs.

Ridge to Reefs is based in the Chesapeake Bay region of Maryland and has conducted watershed restoration activities throughout the world, including in other coral reef priority sites. Ridge to Reefs is well-positioned to provide technical oversight and engineering assistance to this project. Ridge to Reefs' focus is the science and application of restoration and protection measures in coral reef and coastal ecosystems and creating long-term resilience. They have helped build the capacity of local organizations in Puerto Rico and beyond. Their primary responsibilities for the Wahikuli project will include conducting engineering surveys of sites, drafting planning documents, and assisting with filing necessary permits. Ridge to Reefs will also provide feedback and periodic advice to inform adaptive management of BMPs. Ridge to Reefs is currently helping facilitate the NFWF-supported efforts to pilot the restoration BMPs identified through the WMGSSR.

Sunshine Vetiver Solutions supplies sunshine vetiver plants for restoration projects, and provides technical advice on planting, placement, and optimal installation practices to ensure survival of vetiver plants.

The Nature Conservancy (TNC) is collaborating with CORAL and working with a loʻi and land restoration project located at Heʻeia on the North Shore of the Island of Oahu. CORAL works closely with Project Manager Kim Falinski to share lessons learned between our two projects. Lessons learned at Heʻeia have already helped CORAL lay the foundation for an effective monitoring plan in West Maui and have paved the way for obtaining the necessary permits. CORAL is also working with TNC on Maui, where they are advising the project on specific native plants to use for restoration BMPs

U.S. Army Corps of Engineers (US Army Corps): The US Army Corps Pacific Ocean Division, Honolulu District is conducting a hydrologic and hydraulic analysis for West Maui to inform alternatives development. Army Corps previously conducted a reconnaissance study to assess the problem of sedimentation as it related to coral reef health. Dr. Mitchell Moore and Jessica Wiggs-Brunty of the US Army Corps are working on these analyses. US Army Corps is partnering with CWRM to install pressure transducers and turbidity monitors that will provide monitoring data for this project. The US Army Corps also has a regulatory function and administers permits for instream work in accordance with the Clean Water Act.

University of California (UC), Berkeley Landscape Architecture and Environmental Planning Department, College of Environmental Design Under the direction of Professors Matt Kondolf and John Radke, students are assisting this project through researching potential solutions, site selection, and production of the renderings used in this report for the final solution. Students will continue to support the implementation of the recommended solutions in similar ways.

US Geological Survey (USGS) is conducting ongoing stream sediment studies of sources and loading in West Maui and led the surveys that mapped the extent of the legacy sediment problem in three streams in West Maui (Kaopala, Papua, and Wahikuli). CORAL is an active participant in these surveys and works closely with John Stock and Corina Cerovski-Darriau as they compile data to inform restoration actions on the ground. Corina and John also inform CORAL and the Knowledge Sharing Group on appropriate monitoring protocols to determine project effectiveness.

West Maui Ridge to Reef Initiative (WMR2R) represents the culmination of federal, state, and local efforts to create a holistic approach across multiple agencies and organizations to build effective watershed management within priority areas in West Maui. CORAL works closely in collaboration with Watershed Coordinator, Tova Callender. As the WMR2R transitions from planning to implementation, partners like CORAL are taking an active role in developing actionable projects on the ground. CORAL works to complement WMR2R priorities and provide additional capacity. CORAL's Maui Technical Operations Manager, Wesley Crile is a member of the Ridge to Reef Working Group and meets regularly with Tova to ensure that our efforts align with the WMR2R. This will continue during the Wahikuli Watershed restoration project implementation. Tova manages BMP identification and piloting at Wahikuli, which will inform CORAL's proposed activities and vice versa.

30-year-long former employees of Maui Land and Pineapple and Pioneer Mill represent the two primary companies that actively cultivated sugar cane and pineapple on the West Maui lands. Former employees of these companies have a unique insight into the various land uses and practices over the past several decades.

During the initial formation of the Knowledge Sharing Group, participants recognized that there was neither sufficient data describing West Maui's mid-slope landscapes nor field observations to ground truth any existing data to adequately assess sediment sources and potential restoration solution locations. Data were limited because of a lack of Light Detection and Ranging (LIDAR) or other detailed mapping of the region,[9] and field observations were limited because midslope areas are difficult to physically access and have restricted legal access from landowners concerned with liability and risk issues.

To identify suitable solutions, CORAL worked with landowners to obtain the necessary Right of Entry (ROE) documentation to access the landscape. Then, members of the Knowledge Sharing Group collaborated with CORAL to conduct a series of site visits and field observations in Wahikuli and Honokōwai Watersheds to identify viable solutions and potential locations for their installation.

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[9] Five meter Digital Elevation Maps (DEMs) were the highest resolution available, and this was not sufficient to show topography within stream gulches.

Solutions shared in this report include those initially identified by the WMGSSR,[10] but add further refinements based upon what we have learned from the pilots. This report also contains solutions proposed in the West Maui Watershed Management Plans[11] which were completed between 2012 and 2016. In some cases, solutions originally proposed were deemed infeasible for use in West Maui following field observations (such as widespread removal of legacy fill terraces, also referred to as bank sculpting), however, other solutions were ground-truthed and confirmed as viable for addressing sediment transport problems (such as restoration of lo‘i kalo [wetland taro] patches for sediment capture).

[10] Ridge to Reefs (2016) WMGSSR Summary and Recommendations for Restoration Practices
[11] http://www.westmauir2r.com/watershed-management-plans.html

2.1.1 Solution Criteria

Solutions proposed in this report were based on the following criteria developed by the Knowledge Sharing Group in support of restoration goals.

Knowledge Sharing Group
Solution Feasibility Evaluation Criteria

1. Culturally appropriate: Solutions should be respectful of Hawaiian cultural values and include Hawaiian traditional practitioners in design.
2. Financially feasible: Solutions should be feasible within the current and projected fiscal landscape and ideally have a variety of funding sources and mechanisms for sustained financing over the long term.
3. Minimal permitting burden: Where possible, solutions should be designed so as not to require stream alteration permits or other extensive and lengthy permitting processes.
4. Low maintenance burden: Solutions should ideally not require extensive maintenance recognizing the limited capacity of County and State agencies to support ongoing maintenance of infrastructure.
5. Provide multiple benefits to the community: Recognizing that broad scale support for any solution will require the support of multiple community stakeholders, solutions should be designed to provide a suite of benefits to a wide array of stakeholder groups. Examples include: hiking trails, access to resources for traditional practitioners, physical and emotional reconnection to the landscape, parks, and other community amenities.
6. As 'natural' as possible: Following principles of Low Impact Design, solutions should work with the landscape's natural systems, hydrology and ecology to 'heal' and restore degraded lands and kick start natural regenerative processes. This approach will favor the use of 'soft engineering' like plants and small ponds over hardscapes like concrete stream channelization, and large scale dams and basins.
7. Using a treatment train approach: Instead of major investment in one solution (like a massive in-stream retention basin located at the mouth of a stream) the stormwater treatment burden would be spread out among a number of smaller interventions and decentralized throughout the watershed. Solutions should be located at 'bottlenecks' or strategic places within the watershed where pollution runoff is concentrated.

3. TECHNICAL SOLUTIONS

Through engagement with the Knowledge Sharing Group, extensive consultation with technical experts, field visits and discussions, two types of land-based sediment pollution were identified as priorities for improving nearshore coral reef health in West Maui: 1. landscape erosion and sediment transport to streams and; 2: in-stream legacy sediment 'fill terraces' found along stream banks. The following report outlines nine technical solutions for mitigating these types of sediment pollution.

Solutions for landscape erosion and sediment transport to streams:

1. Stream erosion mitigation using stream corridor riparian buffer setbacks from the top of the gulch
2. Vetiver and native plant sediment traps in road kickouts
3. Vetiver and native plant sediment traps to decommission old agriculture roads
4. Hillslope stabilization using vetiver and native plants[12]

Solutions for in-stream legacy sediment 'fill terraces' found along stream banks:

5. Traditional Hawaiian taro cultivation within a lo'i kalo designed to capture and retain sediment
6. Excess stream water diversion during high flow events into suitable retention/infiltration structures that include the following solutions as appropriate to the site:
   a. Infiltration wells, trenches, or French drains
   b. Retention/infiltration basins (in-stream and off-stream)
   c. Multipurpose area with retention (of stormwater), recharge (of groundwater), and recreation (within a community park amenity).

3.1 Solution Overviews

3.1.1 Preliminary Design of Restoration Solutions & Site Selection

Specific sites chosen for pilot implementation of solutions described in this report were selected following extensive field visits by knowledge sharing group members and other technical experts in 2016 and 2017. Sites were prioritized based upon the following criteria:

[12] See https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026353.pdf

- Actively eroding as evidenced by sheet flow rivulets and other observed landscape features
- Hydrologically connected to the stream/gulch, actively conveying sediment to the gulch/stream
- Relative runoff drainage/volume contribution. Larger drainage areas were prioritized over relatively smaller drainage areas
- Likelihood of greatest sediment mitigating effect
- Low or no interference with current or future intended land uses once installed

3.1.2 Solutions addressing landscape erosion and sediment transport to streams

Degraded agricultural landscapes continue to contribute sediment laden runoff to stream channels. These landscapes consist primarily of fallow sugar cane and pineapple fields with bare exposed soils, crisscrossed by an extensive network of disused and unmaintained dirt agriculture roads. Roads and fallow fields are active sources for sediment transport to streams that flow into the ocean.

Solution 1: A stream corridor riparian buffer setback from the top of the gulch to prevent erosion into streams.

The Knowledge Sharing Group recommends that riparian buffers of at least 100 feet be initiated as measured from the top of stream gulches out into adjacent fields. Buffer zone implementation represents the single most impactful, simple and cost-effective recommendation contained within this report.

Riparian areas are the lands adjacent to rivers and streams. The benefits of riparian setbacks or buffer zones along stream corridors are widely recognized by worldwide restoration experts as beneficial to stream health and ecosystem function. Riparian buffers are a zoning tool that local governments can use to maintain riparian functions as communities grow and land uses change over time. When properly managed in a vegetated natural state, these areas stabilize stream banks, limit erosion, reduce flooding, and filter and settle out runoff pollutants coming from the surrounding landscape.

Maui currently has no riparian setback requirements along streams, waterways, gulches or cliffs. Protecting these areas and limiting activities within a setback can prevent hazardous siting of new development on riparian cliffs and highlight areas for targeted restoration efforts. Throughout West Maui, agricultural access roads were constructed within this proposed buffer zone, often as little as five feet away from the gulch edge. Roads now channel stormwater and sediment into the gulch. When pineapple and sugar cane fields were graded and leveled, soil was often pushed off the gulch edge or left precariously poised at the edge as 'push piles' ready to fall into the gulch at the slightest disturbance. Gulches were also used as convenient disposal sites for everything from disused farm equipment and cars to boulders, polyvinyl chloride, and plastic irrigation piping.

The Knowledge Sharing Group recommends that riparian buffers of at least 100 feet be initiated as measured from the top of stream gulches out into adjacent fields. As former agriculture land in West Maui is gradually converted into residential housing, a concerted retreat of any development activities within this setback zone becomes even more important because of predicted extreme weather associated with climate change as well as the vulnerability of buildings perched near the gulch edge.[13] Retreat of development activities and active efforts to restore and revegetate this area will have substantial positive impacts on stream water quality and sediment transport to the ocean.

Phases for solutions 2-4: (vetiver sediment traps)

Implementation of Solutions 2 through 4 requires two phases. The first phase involves constructing vetiver grass sediment trap and stabilization BMPs at strategic locations within Wahikuli and Honokōwai Watersheds to capture and hold sediment at its source—eroding hillsides, dirt roads, and bare earth areas—before it enters streams. Vetiver grass is a popular plant used for restoration throughout the US and other geographies. It has very long roots which help to secure sediment in place and sink rainwater deep into the ground. The 'sunshine' cultivar of vetiver is specifically recommended for use in Hawaiʻi as it has low invasive potential, produces sterile seed, and has been approved by the USDA for use in a restoration context in Hawaiʻi. The second phase involves planting native plants to further stabilize accumulated fine grained sediments and restore native ecosystem function.[14]

These solutions utilize vetiver grass because it improves the soil fertility by increasing infiltration of stormwater and stabilizing soils with up to three-meter deep root systems. By improving growing conditions with vetiver, native plants can reestablish because current high-sedimentation inputs during heavy rain events are reduced and a productive topsoil base is established. Prioritized sites for vetiver and native plant sediment trap BMPs are illustrated in Figure 1.

[13] A 2012 report, *Facing Our Future: Adaptive Planning for Sea-level Rise in Maui and Hawaii Counties* makes the specific recommendation that Maui County, "Establish riparian buffers (setbacks along streams, ephemeral waterways, gulches) [because] there currently are no setbacks for development that is sometimes hazardously sited on riparian cliffs." (http://seagrant.soest.hawaii.edu/facing-our-future-adaptive-planning-sea-level-rise-maui-and-hawaii-counties).

[14] WMGSSR, 2016. West Maui Stream and Gulch Sediment Stabilization Roundtable Summary and Recommendations for Restoration Practices. Attached with this report.

Figure 1: Map pinpointing the locations of proposed BMPs in Wahikuli Watershed (green symbols).

Phase I: Vetiver and Native Plant Sediment Traps with Half-Moons

Vetiver sediment traps, installed as a series of half-moons, are known to effectively retain sediment being transported into streams from former agricultural lands (Figure 2). Because sediments in West Maui are lost at higher rates from abandoned roads with heavily compacted soils (fine particulate sediment) and from former pineapple fields (directed runoff to stream gulches), the Knowledge Sharing Group recommended prioritizing vetiver installations in these areas.

Historic field drainage practices were designed so that sugar cane fields drained back to the field and pineapple fields drained into adjacent stream gulches. This practice has exacerbated sediment export from fallow pineapple agriculture areas. To restore these areas, the Knowledge Sharing Group recommended planting vetiver in a series of at least three rows to help attenuate both coarse and fine sediment particles. Using multiple rows of vetiver creates optimal conditions for fine-grained sediment to settle out of storm water, as evidenced by sediment samples taken from projects in Puerto Rico as well as initial samples from pilot sites in Wahikuli.

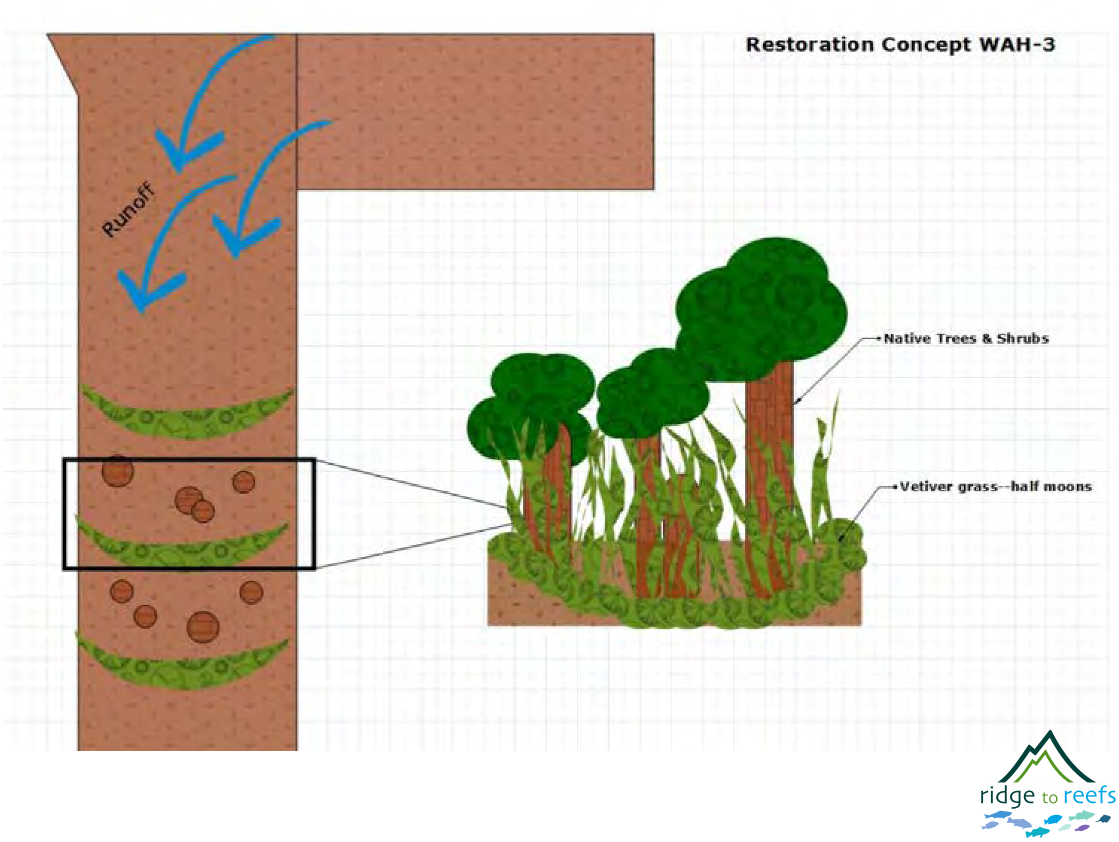

Figure 2: Design concept for using vetiver half-moons and native species to control runoff. Water flows into half-moons and is filtered by plants. Photo credit: Ridge to Reefs.

Figure 3 illustrates sediment accumulation data from a similar installation in Culebra, Puerto Rico consisting of three vetiver half-moons planted in series one in front of another.[15] The sediment samples analyzed showed that as water moved through each subsequent vetiver half-moon within the series of three (first through TWN-1 then through TWN-2 and finally through TWN-3), finer and finer sediment grains were captured. Planting half-moons in series means that sediment that is not captured by the first can be captured by subsequent half-moons, and that finer grained sediment (silt and clay) settles out later in the system. The number of half-moons that should be planted is determined by restoration experts to maximize the amount of fine grained sediment captured on a specific site. Fine-grained silts and clays are the important particle sizes to capture when seeking to reduce impacts to coral reefs as they are the most damaging to reef health.[16]

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[15] Ridge to Reefs: http://www.ridgetoreefs.org/

[16] Storlazzi, C.D., Norris, B.K. and Rosenberger, K.J. Coral Reefs (2015) The influence of grain size, grain color, and suspended-sediment concentration on light attenuation: Why fine-grained terrestrial sediment is bad for coral reef ecosystems 34: 967. doi:10.1007/s00338-015-1268-0

Sample Identification	Percent Sand	Percent Silt	Percent Clay	Textural Classification
TWN-1	74.0	16.0	10.0	Sandy Loam
TWN-2	66.0	20.0	14.0	Sandy Loam
TWN-3	22.0	52.0	26.0	Silt Loam

Figure 3: Effectiveness data collected in Culebra, Puerto Rico.

Phase II: revegetating with native plants

Consultations with native plant experts from MCL, as well as botanists at TNC, has helped identify a short list of native species suitable for revegetation in Wahikuli Watershed. To acquire these plants, restoration experts recommend collecting seed stock native to each watershed and propagating plants in a greenhouse to maximize survival. Collecting seed from the specific location of the plants' eventual out planting ensures the propagation of genetic stock that is uniquely adapted to the specific conditions and microclimates found at each restoration site. As sites at varying elevations and growing conditions are selected for restoration, MCL and TNC recommend continued engagement with their native plant experts to identify additional suitable plants and their support for collecting and propagating seeds.

Plants recommended for Phase II restoration in Wahikuli Watershed include: Hawaiian Sandalwood (*Santalum freycinetianum*), ʻAʻaliʻi (*Dodonaea viscosa*), Koa (*Acacia koa*), ʻŌhiʻa lehua (*Metrosideros polymorpha*) (Figure 4), and Naio (*Myoporum spp.*)

Figure 4: Native Hawaiian plants like this Ohia Lehua tree is one species recommended for second phase revegetation at vetiver restoration sites.

Solution 2. Vetiver and native plant sediment traps in road kickouts

A road 'kickout' is a standard road building and maintenance practice utilized on agricultural dirt roads nationwide. Kickouts are designed to channel stormwater off of the road surface (Figure 5). However, when used in Hawaiʻi in steep, highly erosive areas next to stream gulches, kickouts become major delivery mechanisms for sediment to adjacent gulches and hence to the nearshore environment. A recent study led by the University of Hawaiʻi (UH) confirms that these roads and the surrounding landscapes supply fine-grained sediment to gulches and streams, depositing significant sedimentation on coastal reefs. This study also identified particular locations in the Honokōwai and Wahikuli watersheds as most prone to this type of sediment transport.[17]

During reconnaissance surveys of Honokōwai and Wahikuli Watersheds conducted throughout 2016, CORAL and our partners identified road kickouts as significant contributors of sediment to the stream gulch.

Vetiver, when planted on road kickout contour lines,[18] can trap sediment and prevent it from being conveyed into the stream gulch. It can also effectively filter and sink water flowing off of the road, thereby meeting road maintenance goals without compromising sediment mitigation objectives. Implementing this solution in West Maui provides an opportunity to test and improve upon this technique for use more broadly in Hawaiʻi.

With support from NFWF, Ridge to Reefs collaborated with CORAL and others to pilot road kickouts in Wahikuli in November 2016 (Figure 6). Preliminary data collected at three pilot vetiver half-moon sites installed in Wahikuli indicate a similar distribution of particle sizes retained as illustrated in Figure 3.

Figure 5: Aerial photograph showing dirt road and 'kickouts' which deliver road runoff and sediment into the gulch. The left side of picture leads downslope towards the ocean. Preliminary surveys identified 65 kickouts in Honokōwai Watershed and 55 in Wahikuli Watershed actively contributing sediment to adjacent streams.

[17] Kirsten L.L. Oleson & Megan Barnes (2016). Evaluating potential solutions to West Maui's Coral Reef Decline: Feasibility of ecological models to evaluate solutions. Department of Natural Resources and Environmental Management, University of Hawaiʻi Mānoa. Draft Final Deliverable.
[18] The line joining equal elevation on a surface

Figure 6: Vetiver half-moon pilots planted in a road kickout in Wahikuli under Ridge to Reefs' NFWF grant. This photo was taken one month after installation and already shows significant volumes of sediment retention.

Solution 3. Vetiver and native plant sediment traps used to decommission old agriculture roads

Closing roads using structural methods (barriers) such rocks, logs, or vetiver plantings can improve soils and attenuate runoff. The West Maui Watershed Plans identify hundreds of miles of poorly maintained and disused former agricultural roads as major sources of sediment transfer and pathways for channeling stormwater runoff. These roads are severely compacted, and the soils have lost most, if not all, of their stormwater infiltration capabilities. In coordination with DLNR, disused roads have been identified for decommissioning, and roads likely to stay in use will be improved using cross-swales (water bars) and vetiver traps to minimize downslope transport of eroded sediments. Roads for stabilization and closure are prioritized based on 1) public use needs, 2) slope, 3) percentage of sand, silt, clay, and stone, 4) erosion and infiltration rates, and 5) likelihood of transport to streams/gulches based on models developed by Ramos-Scharron in 2009.[19]

Similar in principle to the solution outlined above for road kickouts, lines of vetiver can be planted on contours across disused roads. These lines serve to interrupt and spread stormwater flows, capture sediment, and infiltrate water safely into the ground. As plants mature, and especially if coupled with stones or other physical barriers, they effectively delineate a road as decommissioned. It is important to conduct stakeholder engagement with any potential road users such as fire crews, rangers, illicit dirt bikers, hikers, and horseback

[19] A review of surface erosion and sediment delivery models for unsealed roads 2010 CE Ramos-Scharron - Environmental Modelling and Software

riders to help select sites and ensure potential users understand the purpose of the plants so they are left intact. Signage can also be useful to convey this information. We prioritized roads for closure based upon two criteria:

1. Roads with high levels of erosion and deep ruts that render them dysfunctional as a road
2. Those which have clearly not been used for at least two years.

CORAL and partners implemented a pilot of this technique at one site in Wahikuli during June 2017. We anticipated strong runoff flows as evidenced by the severe erosion present. To accommodate these intense flows, we planted vetiver rows close together with rocks piled downslope behind the plants to prop them up and provide additional barriers to mitigate the velocity of stormwater. We also planted vetiver following contours of the landscape to allow flows to spread out along the line of vetiver instead of concentrating erosive effects in one spot.

Solution 4. Hillslope stabilization using vetiver and native plants

To stabilize hillslopes, we recommend the NRCS Practice 601 for vegetative barriers.[20] This practice involves planting vetiver across the hill on contour to stabilize actively eroding hillslopes, capture sediment, and infiltrate sheet flowing stormwater runoff into the ground. The NRCS recommends planting rows of vetiver along contour lines with vertical distances of six feet between lines (See Figures 7 and 8). In addition, this practice has the potential to foster reintroduction of well adapted Hawaiian native plants and trees that can be planted behind the vetiver lines.

CORAL and partners tested this technique in June of 2017. We used small vetiver 'slips' or bare root cuttings and planted them close together so that the cuttings touched one another. Dense planting like this provides a physical barrier which can begin capturing sediment right away, even before vetiver takes root and grows.

For both pilots, we will measure sediment captured at these sites once the rainy season starts.

[20] See: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_036982.pdf

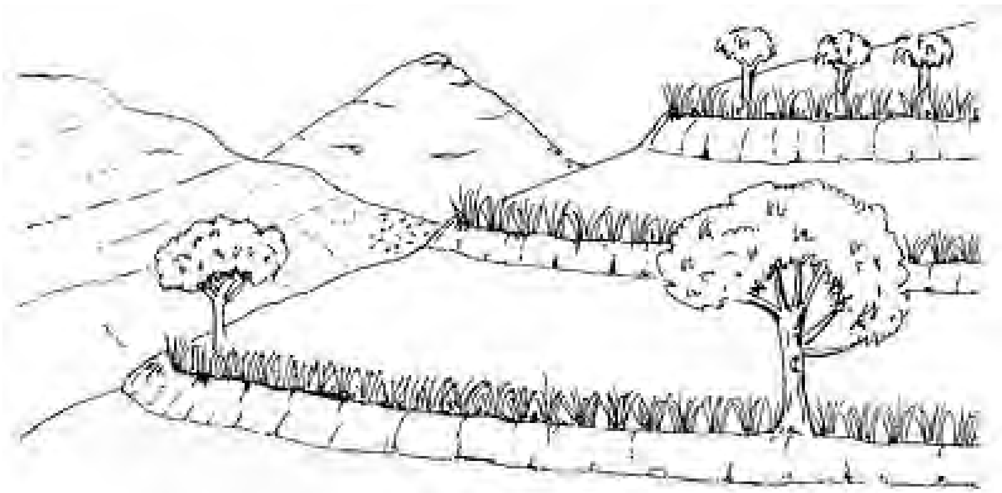

Figure 7: Vegetative Barriers (such as vetiver) planted on contour for topsoil protection and sediment runoff capture (USDA NRCS Practice 601). [21]

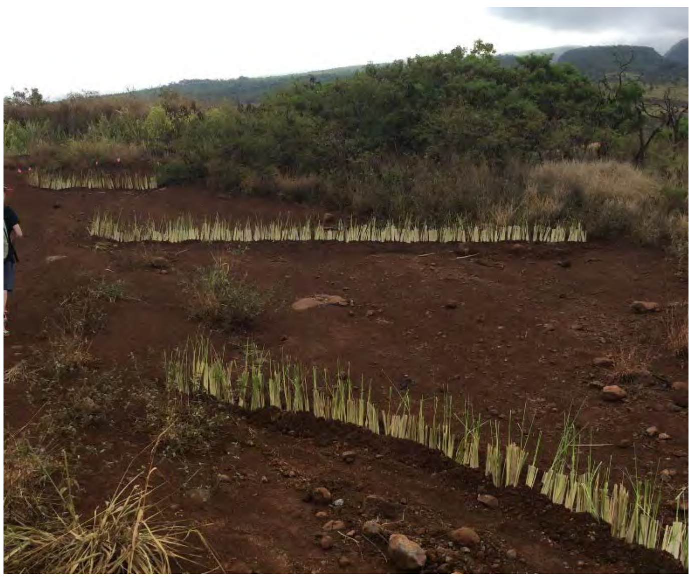

Figure 8: Example of vetiver planted on contour for hillslope stabilization following spacing slope and guidelines outlined in NRCS practice 601.

Permitting, maintenance, and budgetary considerations

Planting of vetiver and native plants on previously disturbed agriculture areas does not require a permit, and can be accomplished with a sufficient volunteer workforce. This makes vetiver and native plant solutions the easiest to accomplish in terms of installation and navigation of regulatory hurdles. Permission need only be secured from the landowner, and long-term maintenance of sites is not required once plants have become established. Depending on the time of planting, initial watering may be required for the first 2-3 months following planting. This can be accomplished with on-site irrigation, rain catchment, or

[21] See: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_036982.pdf

water delivery to the sites. Periodic visits to the sites are recommended to measure overall effectiveness, and to assess sites for readiness of introduction of native plants.

Table 1: Sample budget to install 4 vetiver half-moons 15ft long assuming two months of watering time *(note that road kickout vetiver installations will likely need to be smaller than 15 feet on average. Usually 3 rows 5-10 feet long is sufficient).*

Item	Cost
Total installation	$3,610
Total maintenance	$7,660
Project Management	$4,000
TOTAL	**$15,270**

Monitoring and Evaluation

The following monitoring activities will enable evaluation of the effectiveness of vetiver BMPs to reduce sediment and nutrient pollution in Wahikuli and Honokōwai streams.

Monitoring Goal: Reduction of sediment delivery to streams through the use of vetiver and native plant BMPs. Target is 50 percent reduction of sediment delivery.

Table 2: Monitoring Metrics

Metric	Methods	Frequency/ Duration	Target(s)
Acres of catchment area receiving improved filtration	Estimated using a topographic survey of the contributing drainage area for each installed vetiver BMP	Once at installation of BMP	50% of catchment area consisting of former agricultural lands[22]
Sediment accumulation at each BMP	Sediment depth will be monitored and measured using a combination of stationary erosion pins and jute matting (to delineate initial ground level) within each BMP.	Once every two months and following significant (> 1in.) rain events	Baseline has not been established. Based on each BMP's contributing drainage area a corresponding sediment accumulation rate should be expected[23]

[22] Wahikuli watershed is 6.1 square miles in size (representing 16.8% of the West Maui priority site land area). Of this total, 40.6% or 2.5 square miles are degraded agricultural lands. These 2.5 square miles represent the location where CORAL will implement 26 restoration BMPs to reduce sediment and nutrient land-based pollution. Our target is to install strategically placed BMP's that will effectively filter stormwater from 50% of this area (~1.25 square miles of catchment area).

[23] These rates will inform suitable targets that can be expected in similar projects in watersheds with comparable rain and land use characteristics in the State of Hawaii.

Sediment grain size	Analysis of sediment grain size/consistency to determine effectiveness of fine grain removal (fine suspended sediment is considered most damaging to reef ecosystems in West Maui)	Following significant (> 1in.) rain events (occurs approx. every 3-4 months)	Baseline has not been established. Based on each BMP's contributing drainage area, and the overall % of fine sediment contained within the dominant soil type
Turbidity in Wahikuli and Honokōwai Streams	Using pressure gauges and turbidity instruments, two stations will be set up and will measure stream stage and turbidity at the mouths of Wahikuli and Honokōwai Streams.	Continuously during and following significant (> 1in.) rain events while the stream is flowing	50% reduction in turbidity as a proportion to the overall stream stage/volume
Number and linear feet of vetiver and native plant sediment traps installed to effectively filter stormwater runoff	We will record the number of sediment traps installed and measure the linear feet for each half-moon	Measured once at installation and again following any plant loss	~1,000 linear feet of vetiver half-moon sediment traps planted (25 sediment traps x ~40 feet per trap)

Discussion

Piloting the approaches described above will improve our understanding of the efficacy of strategically placed vetiver BMPs within a watershed. Analysis will include stream flow, catchment area, sediment accumulation, and turbidity reduction as an indication of efficacy. Specifically, we recommend measuring the amount of sediment captured across a catchment area under various flow regimes with special focus on fine grain sizes because those are the most damaging to coral reefs and contribute to brown water alerts. Data will be analyzed against the actual size of the BMP installed (for example, number of plants and area/rows/length of sediment half-moon). Comparisons of vegetation types used in the BMPs is recommended to improve understanding of how the type of vegetation can influence outcomes. Evaluating the efficacy of these BMPs is critical to informing other and future watershed restoration efforts.

Table 3: Three-year work plan installing 20 vetiver BMPs

Activity:	**Year:**	**1**				**2**				**3**			
	Quarter:	1	2	3	4	1	2	3	4	1	2	3	4
Construct vetiver sediment trap and stabilization to prevent sediment movement.													
Landowner coordination and onsite construction, supervision and project management		■	■	■	■	■	■	■	■	■	■	■	■
Conduct surveys of proposed BMP sites identified by stakeholders. Select specific sites for restoration based on priority ranking. Evaluate safety hazards		■	■										
Conduct engineering and design for BMPs		■	■										
Collect and propagate seeds for locally specific plants for restoration		■	■										
Install first 10 BMPs						■	■	■					
Conduct adaptive management to optimize BMP performance							■	■	■				
Install next 10 BMPs									■	■	■		

3.1.3 Solutions that address in-stream legacy sediment 'fill terraces' found along stream banks:

Legacy fine-grained 'fill terrace' sediment deposits that were pushed into stream gulches during plantation agriculture days are now found along stream banks (see Figure 9). This material is deposited into streams when stream flow reaches a certain volume and velocity, and then is transported downstream to the ocean causing all too familiar 'Brown Water Days' (see Figure 10). Once this sediment is entrained in the stream, it is very difficult to settle out or remove from the water. Estimates indicate a minimum of 72 hours retention time at zero velocity is needed in order to allow fine grains to settle out of suspension.

Figure 9: Shows a typical legacy sediment 'fill terrace' deposit found along stream banks in Wahikuli.

In response to the stream legacy sediment problem, the Knowledge Sharing Group considered the following potential solutions:

1. Physical removal of deposits (sometimes described as 'bank sculpting'): Legacy fill terrace deposits are extensive, and are found along 50-70 percent of West Maui stream lengths. They vary in thickness from a few feet to several yards in thickness. Streambeds are also difficult to access with heavy equipment therefore while it may be

possible at a few locations along the stream bed, widespread physical removal of these deposits is generally not feasible.

2. Capping of deposits: This could be accomplished with a sprayed concrete mixture such as 'shockcrete' but again, due to difficult access, the unnatural look of concrete, and the wide extent of the problem, we do not recommend this practice as a preferred approach.
3. Stabilizing with plants: Plants could potentially be used to stabilize fill terrace deposits, however more research needs to be conducted to determine desired plant types and characteristics. It is also unclear if plants could adequately hold onto sediment deposits during high stream flows when the erosive effects of stream water are at their highest.
4. Stream channel restoration: In this scenario, excised stream channels (those cut deep into the surrounding landscape) are filled with sand, gravel or other naturally porous material, effectively capping fill terraces, and reconnecting streams with the surrounding floodplain to provide excess water storage and mitigate high flow flooding downstream. While this solution could be considered where funding and access are readily available (such as where streams flow through neighborhoods, parks or urban areas), because the extent of the problem is so great, as well as the high expenses associated with this solution, make it unfeasible on a broad scale.

Figure 10: Brown Water event in West Maui caused by stream sediment inputs.

Recommendations

CORAL, CWRM, and the US Army Corps have installed stream gauges and turbidity measurement devices in Wahikuli and Honokōwai Streams in an effort to pinpoint the exact volume and velocity threshold that enables the stream to pick up these sediments. Once this threshold is determined, solutions that reduce water volume and speed during high flow events and keep flows safely below the threshold can be installed along the stream reach.

These types of solutions are collectively referred to as ‘high flow diversions’ in that they only divert water as stream levels rise and approach a critical turbidity threshold. Diverted water can be used for irrigation, infiltrated into the ground through structures that aid in aquifer recharge, or returned to the stream following the high flow event. These structures can also act as sediment settling or retention basins. Detailed descriptions of these options are found below.

Solution 5. Traditional Hawaiian taro cultivation within a lo‘i kalo designed to capture and retain sediment

In Honokōwai Watershed, the Knowledge Sharing Group recommend using restored wetland lo‘i kalo to retain sediments. Surveys within Honokōwai Valley show extensive historic lo‘i kalo infrastructure including stone walls and auwai (irrigation channels used by Hawaiians in their agriculture). While these sites are currently overgrown with invasive plant species such as guava, bamboo, and Christmas berry, with a dedicated labor force, they could be cleared and replanted with taro. At least three sites have been identified within Honokōwai Valley where lo‘i could be restored to aid in sediment capture and flood mitigation (Figure 11).

Figure 11: Images from Honokōwai Valley showing historic stone walls of lo‘i kalo that are suitable for restoration.

To restore lo‘i kalo structures and optimize them for sediment retention, ponds of varying sizes are installed along a stream corridor, or in its floodplain. Often lo‘i kalo use an auwai, which brings water into the lo‘i from the stream. Ponds are delineated and separated from one another with stacked stone walls that allow water to permeate between ponds. The sediment captured in a lo‘i provides an ideal wetland substrate for traditional Hawaiian farming of kalo (taro plants) and numerous other crops important for consumption, utilitarian uses, and cultural practices (Figure 12).

Figure 12: Left: Kalo growing in a typical lo'i. Right: Example of a historic lo'i found in Iao Valley, Maui.

Similar in structure to terraced rice paddies, loʻi play an important role in stream restoration and improve water quality by trapping nutrient and sediment pollutants.[24,25,26] Loʻi slow the velocity of stream water, thus reducing its erosive effects, increasing water retention times, and allowing sediment to settle out of suspension. Loʻi also expose more water surface area to sunlight, speeding up biological processes within the water to increase photosynthesis and nutrient uptake by plants.[27] Research shows that sediment retention and pollutant uptake in detention basins is significantly higher in multi-tiered/wetland systems that incorporate plants (such as terraced taro patches) than in conventional flood control basins with no elevation change and no plants.[28] Precisely how much sediment a loʻi can capture, its Sediment Trap Efficiency (STE), is based on factors including size, shape, configuration, and the number and type of plants it contains. It is not uncommon for a small pond or series of ponds at varying elevations to remove 90-100 percent of the sediment suspended in the water that flows through the ponds.

Stakeholders have suggested loʻi as a viable solution for reducing sediment pollution in West Maui for some time.[29] Assuming a conservative dry season calculation of sediment loads for a typical intermittent stream in West Maui, a relatively small loʻi (<1 acre) could prevent an

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[24] The Nature Conservancy (2015). Matt Miller Can Traditional Agriculture Restore the Reef? Cool Green Science. Smarter By Nature.

[25] Verstraeten, G. and Poesen, J. (2000). Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield. Progress in Physical Geography. Vol. 24; 219

[26] White, P.; Labadz, J.C. and Butcher, D.P. (1996). Sediment yield estimates from reservoir studies: an appraisal of variability in the southern Pennines of the UK. In Walling, D.E. and Webb, B.W., editors, Erosion and sediment yield: global and regional perspectives (proceedings of the Exeter symposium, July 1996). IAHS Publication 236, Wallingford: IAHS Press, 163–74.

[27] Pinkham, R. (2000). Daylighting: New Life for Buried Streams. Rocky Mountain Institute, Old Snowmass, CO

[28] Hogan, D. M. and Walbridge, M. R. (2007). Best Management Practices for Nutrient and Sediment Retention in Urban Stormwater Runoff. Journal of Environmental Quality.

[29] West Maui Watershed, Section 905(b) WRDA (1986). Analysis Report Reconnaissance, Final Stakeholder Coordination report; "Construct or restore sediment catchment, wetland, and lo'i kalo for sediment capture."

average of 275 pounds of sediment per day[30] from entering the marine environment. Monitoring at restored loʻi in Honokōwai will provide actual STE values at each loʻi and BMP installed. The known STE will allow us to evaluate success of achieving our target to reduce sediment flowing through the loʻi by 50 percent*.* Furthermore, traditional agriculture is an important sustainable food source and a symbol of a vibrant Hawaiian cultural renaissance.

The proposed design would utilize sediment traps above the loʻi to capture both large and small sediment particles followed by a series small ponds where taro is grown (see Figure 13). The taro plants' broad leaves combined with the dense vegetation in the trap above the loʻi will promote the uptake of nutrients and settlement of fine particles. The flow path of water through the taro patches is maximized to promote both sediment deposition and nutrient uptake.

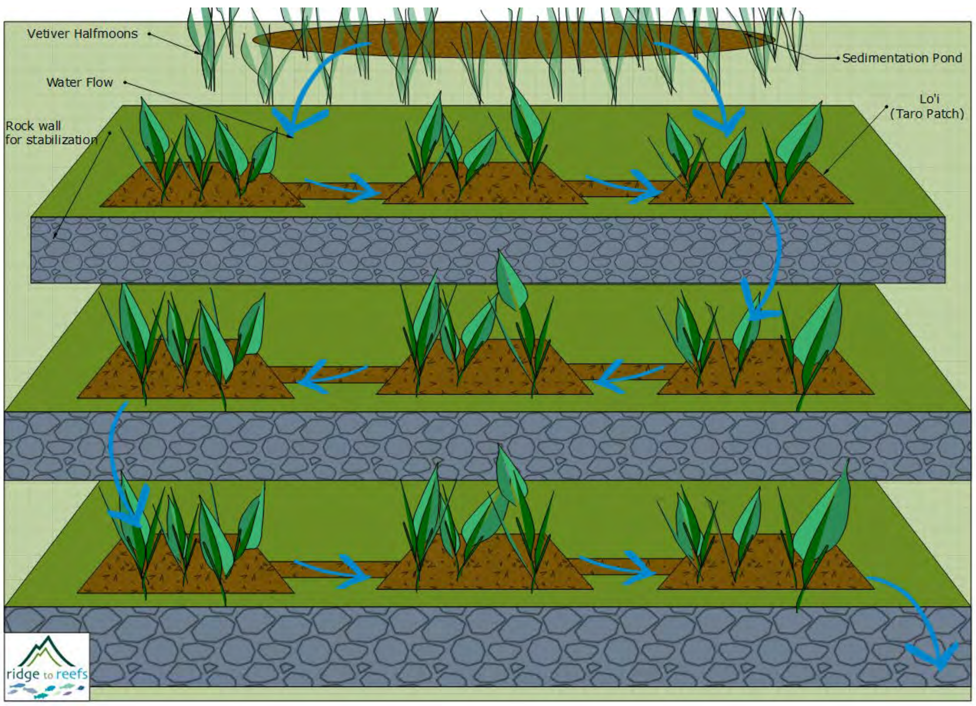


Figure 13: The proposed design would utilize vetiver sediment traps ahead of the loʻi to capture both large and small sediment particles followed by a series of ponds where taro is grown with the dense vegetation helping to promote further settling of fine particles.

Permitting, Maintenance, and Budgetary Considerations

The regulatory process by which historic fallow loʻi can be restored to active cultivation and potentially utilized to reduce sediment transport and restore watershed function is very site specific, and involves issues of land ownership, traditional land claims, and traditional water

[30] For example: Kaneohe Steam on Oahu has a total maximum daily limit (TMDL) for total suspended solids (TSS) of 500 kilograms/day. Diverting 25percent of this stream's volume into a suitably sized lo'i with 100percent STE would result in the removal of 125 kg/day of sediment)

use the details of which are beyond the scope of this report. What follows is a discussion of the regulatory requirements based on our experience preparing to restore loʻi in the Honokōwai Watershed.

In early 2016, CORAL began working closely with CWRM, who were tasked with determining authorized allocation of surface water resources for the State. In 2013, CWRM began the process of determining 'low flow standards' for the streams in West Maui. The low flow standard determines the volume of water that must remain in (or be returned to) the stream system. This value is used to determine various "off stream" uses for that water such as agriculture, commercial activities, or drinking water. During the days of sugar cane and pineapple cultivation in West Maui, an intricate system of irrigation ditches, tunnels, and stream diversions was utilized to take water from streams on the windward, wet side of the island, and deliver it to the leeward, dry side, of the island to water crops. With the end of commercial pineapple and sugar cane cultivation in Maui, this infrastructure is no longer serving its intended purpose.

Over the past decade, the necessity and public benefit of this continued stream diversion has come into question. Environmental groups, grassroots organizations and traditional Hawaiian farmers have called for ending stream diversion in support of returning water to natural streams to support stream ecosystem function and traditional cultivation of loʻi kalo. In West Maui, the Honokohau Ditch system diverts a high percentage of the stream flow from Honokōwai Stream. Currently, the stream's flow reaches below the diversion only during high rainfall events. This is problematic for sustainable cultivation of loʻi kalo within this area, because loʻi require cool consistently flowing water. MCL is working to restore traditional loʻi kalo within Honokōwai Valley, but these systems will require consistent water before they can be actively cultivated.

CORAL is collaborating with CWRM to install stream gauges within Honokōwai and Wahikuli Streams. These gauges will determine average wet and dry season flows to these streams, and the volumes will be used to determine designated uses. Traditional loʻi kalo cultivation is a protected use under State law, and through our communication with CWRM officials, we are confident that the diversions in Honokōwai Stream will be decommissioned in the future allowing water to flow for the full length of Honokōwai Stream. While this process may take a year or more, work clearing loʻi of invasive species, repairing stone walls, and removing accumulated debris from ponds can begin in preparation for active cultivation. We are in close contact with the State Historic Preservation Department (SHPD) and are working closely with traditional Hawaiian practitioners through MCL to ensure respect for sacred sites. Restoration activities will not require a permit from SHPD provided we are restoring existing loʻi (and not constructing new loʻi), the total size of each designated project does not exceed one acre, and excavation/digging goes no deeper than four feet. Although a permit is not officially required, we plan to provide regular communication with State archaeologists, interested kupunas (elders) in the area, Maui/Lanai Burial Commission, the Aha Moku Council, and other Native Hawaiian/indigenous people's groups or interested parties.

Maintenance

The process to clear disused loʻi of invasive trees and plants is labor intensive, but can be accomplished with a dedicated workforce consisting of paid laborers or volunteers. Once loʻi are cleared, they can be replanted with a suitable taro cultivar and harvested on an 11-month cycle. Regular maintenance during this time is essential for a successful harvest. Maintenance activities include: repairing rock walls, adjusting water flows to maintain optimal function of the system, weeding the ponds, and keeping pathways and access areas clear and free of invasive plants.

Table 2: Budget for initial restoration and 2-year maintenance of a one acre loʻi kalo

Pilot Project, 1 acre restored loʻi	**Total**	**Year 1**	**Year 2**	**Year 3**
Project management (cultural and technical advisor)	98,000	35,000	35,000	28,000
Field crew. *Note that figures are based on assumption that fallow loʻi are overgrown and require clearing and that rock walls require significant repair. Most of these costs can be reduced by use of volunteers who are managed by a paid coordinator.*	100,000	40,000	40,000	20,000
Equipment and mobilization (for heavy rock placement, clearing access routes, and removal of accumulated debris in the ponds)	32,500	16,250	16,250	
Irrigation and supplies (supplemental water is necessary until water is released into Honokōwai stream)	6,000	4,000	1,000	1,000
Taro starts 'huli' (initial starts must be purchased, while subsequent years can be supplemented from each preceding year's harvest)	10,000	5,000	5,000	
Facilities and base-yard to house equipment and tools	36,000	12,000	12,000	12,000
Total	**282,500**	**112,250**	**109,250**	**61,000**

Table 3: Monitoring Metrics

Metric	**Methods**	**Frequency/ Duration**	**Target(s)**
Sediment accumulation within each loʻi	Sediment accumulation will be measured using sediment 'pods' (sediment traps) placed throughout the loʻi. Additionally, standardized concrete pads or metal 'bottom' structures will be placed throughout the loʻi to delineate initial ground level within the	Every six months following completion of the loʻi and following significant storm events (>1 in rainfall or when inflowing stream turbidity reaches a	Baseline has not been established. However, we expect sediment accumulation rates to be proportional to the volume of water flowing through the loʻi.

	lo‘i so sediment depth can be measured consistently relative to a ‘fixed’ substrate.	threshold of ~2 NTU)	
Nutrients and turbidity	Nutrient removal and turbidity reduction will be measured using YSI data sondes placed at the entrance/inlet channel and outlet so we can compare levels for water entering and exiting the lo‘i	Continuously for the duration of the project	50% reduction in turbidity and nutrients measured in water flowing out of lo‘i compared with water flowing in.
Water volume and number of kalo plants	The volume of water flowing through the lo‘i along with the number of kalo (taro plants) will be tracked so we can calculate efficiency	The volume of water will be measured on an ongoing basis and the number of kalo plants planted will be recorded during planting.	There is no baseline for optimal size but through this assessment, we will be able to generate targets for other efforts based on the efficiency of both the kalo at reducing nutrients and the lo‘i at reducing fine sediment[31]
Expenditures (man hours and cash expenditures)	We will track lo‘i kalo farming expenses to help inform the viability and sustainability of this alternative management technique	Quarterly through the duration of the project	NA
Yield: pounds of kalo (taro) harvested within a ~1-acre lo‘i kalo	Yield will be weighed and recorded by type of product (pounds of root; pounds of leaves) to help us understand the long-term viability of using lo‘i kalo for watershed restoration	Measurements will be taken each harvest (cycle is approximately 11 months)	10,000 lbs taro root and 1,500 taro leaf per year

Discussion

The Knowledge Sharing Group recommends use of lo‘i to reduce sediment in adjacent streams. Lo‘i kalo farmers and conservation organizations have expressed interest in using this technique in the future. In accordance with organic standards, no inputs, such as fertilizer or pesticides, will be used for growing taro. Moving forward, for widespread use of

[31] These rates will inform suitable targets that can be expected in other *lo‘i* projects in similar watersheds with comparable rainfall patterns and land use characteristics in the State of Hawaii.

lo‘i kalo in Hawaiian watershed restoration, a model for financial sustainability is required and likely will use a combination of the sale of lo‘i products, agrotourism, and other revenue streams.

Table 4: Suggested work plan

Capture sediment with a modified traditional Hawaiian wetland taro terrace (lo‘i kalo) sediment basin.													
Activity:	Year:	1				2				3			
	Quarter:	1	2	3	4	1	2	3	4	1	2	3	4
Landowner coordination and onsite construction and supervision/ project management		■	■	■	■	■	■	■	■	■	■	■	■
Conduct detailed surveys of areas historically used for lo‘i kalo and evaluate safety hazards		■	■										
Conduct engineering and design for lo‘i		■	■										
Acquire permits or landowner permission		■	■										
Develop lo‘i restoration and ongoing maintenance plan		■	■										
Restore lo‘i by removing vegetation that has overgrown lo‘i terraces, repairing rock walls, and installing auwai or piping to bring water into the lo‘i			■	■									
Milestone: Plant appropriate taro cultivar on a 9-11 month harvest window				■			■			■			■
Facilitate ongoing maintenance program incorporating taro crop cultivation. We recommend using volunteers for these activities.			■	■	■	■	■	■	■	■	■	■	■

Solution 6: Diversion of excess stream water during high flow events into suitable retention/infiltration structures

Extensive field reconnaissance along Wahikuli Stream identified eight locations where high flow diversion interventions or restoration solutions could be implemented (see Figure 14). Field visits are essential because the five-meter Digital Elevation Models are currently the highest resolution maps available for Maui’s non-coastal areas. This level of resolution is inadequate for understanding the floodplains found within gulches and to properly assess the riparian areas along streams for potential restoration solutions. Although there is a strong need for LIDAR or other high-resolution mapping of Maui, the high cost to collect this type of data has limited the level of collection in Maui. It is possible that the use of drone or ground based mapping tools could be used for specific sites.

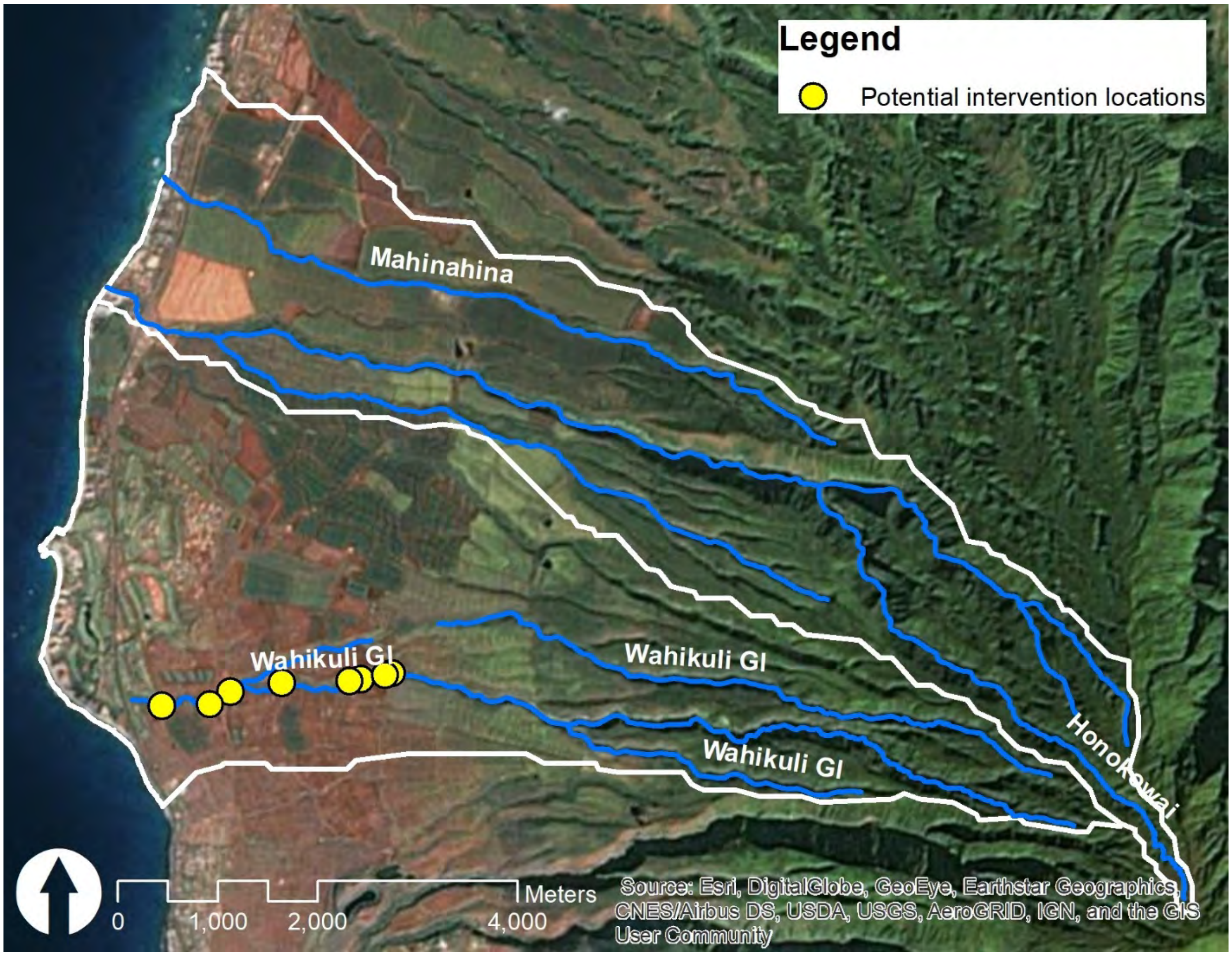


Figure 14: Potential Intervention Locations Based on May 2017 Site Visit (Credit: Watershed and stream data, State of Hawaii Office of Planning)

Sites identified as appropriate for this type of solution along Wahikuli Stream fall into three categories: level riparian floodplains, sloping riparian floodplains, and old road or railway crossings. Initial exploration of other streams in West Maui reveals that these types of sites are also found in other watersheds. Thus, these solutions are applicable in other areas.

Level Riparian floodplains

We categorized level riparian floodplains as sites found alongside streams that are generally level, are at or below the elevation of the existing stream channel, and are greater than one acre in size.

During our assessments, these sites appeared to be former traditional agriculture areas, which were of great interest because of their excellent high flow storage/infiltration potential. With minimal effort, high flows in the stream could be directed out of the channel onto the floodplain and into a suitable retention/infiltration structure or structures (e.g., installing a few well-placed boulders or a very small check dam[32]). As an example, please review the *retention, recharge and recreation* site information under Solution 9.

Figure 15: Shows a level floodplain adjacent to Wahikuli Stream that could easily accommodate a high flow diversion and retention/infiltration structure (the stream channel is indicated by the line of greener vegetation).

<u>Sloping Riparian floodplains</u>

We categorize sloping riparian floodplains as sites that slope downward towards the stream channel. Sloping will make it more difficult to direct water out of the channel, but solutions such as a gravel lined infiltration trenches, infiltration wells, or "French drains" could be used to infiltrate stormwater in these areas.

<u>Old road and railroad crossings or earthen 'bridges'</u>

We categorize these sites as areas with a culvert or tunnel that allows stream water to pass through. These constriction points could be modified to allow for longer retention times and increased water storage capacity.

Solution 6.a: Infiltration Wells, trenches, or French Drains

Underlying geology in West Maui consists of layers of volcanic deposits; some containing rapidly cooled lava that is brittle, crumbly, and contains spaces and cavities, while other deposits that cooled more slowly are more dense. These dense layers do not readily allow water to rapidly percolate, while the less dense layers allow for rapid water infiltration. This geology has the potential to infiltrate significant amounts of water provided

[32] A check dam is a small, sometimes temporary, dam constructed across a waterway to counteract erosion by reducing water flow velocity. Check dams are an ancient technique used since the second century A.D.

engineered wells and trenches are suitably high enough above underlying groundwater tables and the bottoms of wells and trenches can access enough porous (less dense) strata to allow water to pass through. Infiltration wells, trenches, or French drains are all designed to convert surface water into groundwater by sinking excess stream flows safely into the ground. Acting like a 'reverse well', this approach has the added benefit of effectively recharging freshwater aquifers.

Figure 16: Concrete infiltration well

Infiltration (dry) wells are similar in construction to a cesspool. This open-bottomed well structure is installed surrounded by gravel and wrapped in a geotextile cloth to prevent fine sediment from clogging the well, which would reduce infiltration performance over time. Stormwater is directed into the well where it drains effectively into the ground. Infiltration wells can be as simple as a pit filled with rubble or as complex as a prefabricated concrete structure (Figure 16).

An infiltration trench, or French drain, is similar to a well except that it is configured as a long trench filled with gravel or a perforated pipe which spreads water over a larger area. Excess stream water could be directed into a trench, provided the water did not contain significant fine sediment particles which might eventually clog the system.

We dug test pits at one potential site and revealed an overlying layer of compacted clay (Figure 17). To install a functioning trench/drain, it will be important to dig past the clay in order to reach more permeable strata below. Care must be taken to prevent sediment loss during excavation of this clay material because it consists of extremely fine-grained sediment. With either of these systems, it is important to provide pre-treatment that removes any suspended fine-grained sediments. Pre-treatment can include installing pre-filtration wetlands or retention basins before the water goes into a trench or drain. If turbid water is introduced directly into these infiltration structures, fine sediments can clog them and reduce their effectiveness over time.

Permitting, maintenance, and budgetary considerations:

Figure 17: Test pit showing overburden of fine clay (approximately 3-5 feet thick). This layer would have to be breached in order to effectively utilize infiltration wells or trenches.

Any of these solutions will require excavation with heavy equipment and, depending upon their size and depth, may require an underground injection control (UIC) permit as they could be considered Class V wells under the Environmental Protection Agency Clean Water Act which states "A UIC permit is required if stormwater is directed to any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or has a subsurface fluid distribution system" (such as perforated pipe). Additionally, a County of Maui "minor grading permit" would be required, and the depth of the excavation cannot exceed 15 feet. CORAL is collaborating with NRCS technical assistance providers, and there is a possibility that this work could be conducted under an approved conservation plan. In this case, it would be possible to file for an exemption for County permits provided all work is "…shown to be in conformance with standards set forth by the soil and water conservation districts and in accordance with an actively pursued comprehensive conservation program [the details of which are contained within the conservation plan]."

Table 5: Cost estimates for an infiltration trench 20 feet wide, 10 feet deep, 50 feet long

Item	Cost
Project Construction and Management	15,000
Design and engineering	10,000
Site survey cost	5,000
General labor (5 days)	5,000
Course aggregate ($500/truckload (20 truckloads)	10,000
Backhoe equipment rental and operator 5 days	5,000
Trucking costs	3,500
Geotextile fabric	2,000
Contingency costs (15%)	8,250
TOTAL	**$63,250**
Ongoing maintenance (removal of any debris or accumulated sediment) from the structures following any major storm events.	$20,000/year

Solution 6.b.a: Retention/ infiltration basin (off-stream)

Off-stream retention basins can be located in areas where there is a natural depression within the riparian zone adjacent to the stream channel. The size and depth of these depressions depend on the topography of the site. In an ideal situation, little to no excavation would be needed to create these recharge basins, thus avoiding disturbance to loose erosion-prone soils. Diverted excess stream flow would be directed to a recharge basin. This is essentially a depression that can capture and hold a determined volume of water for a set period of time (see Figure 18). Retention basins generally have the following common elements:

- An inlet structure through which diverted stream water enters the basin. This can be either a constructed channel or a buried pipe
- A stand pipe or other overflow structure that acts as a failsafe in the event of excessive stormwater volume
- Maintenance access via a road or ramp that leads down into the basin, and allows for the use of heavy equipment to periodically remove accumulated sediment

Figure 18: Example of an off-stream retention/infiltration basin. High flows from the stream enter the basin, and sediment settles out as water infiltrates into the ground. Overflows are failsafe mechanisms necessary if the basin becomes overwhelmed by excessive stormwater. The access road at the far side of the basin allows for periodic removal of sediment with heavy equipment.

Permitting, maintenance, and budgetary considerations:

Ideally, existing boulders or logs would form natural check dams to control the overflows/high flow diversions of water from the stream. In other situations, existing stream bank overflow points can be utilized. If there are not suitable overflow sites, a "stream channel alteration" permit may be required to construct the high flow diversion structure.

Rather than one large sediment retention basin (as has been done in other West Maui watersheds), a series of smaller basins is recommended because it would be more feasible within the project timeline and regulatory environment. Where possible, we recommend not creating basins with depths that are greater than six feet, so as to avoid a higher level of engineering design and permitting requirements. According to DLNR, "Barriers which will be 6 feet or less in height or which will have a storage capacity not in excess of 15 acre-feet are not considered to be dams and no application is required."[33] In addition, a series of small basins makes the system more redundant by not relying on only one basin to capture sediment and infiltrate water.

Provided the overall footprint of the project remains below one acre, a County of Maui "minor grading permit" would be required. CORAL is collaborating with NRCS technical assistance providers, and there is a possibility that this work could be conducted under an approved conservation plan. In this case, it would be possible to file for an exemption for County permits provided all work is "…shown to be in conformance with standards set forth

[33] Department of Land and Natural Resources, Division of Water and Land Development, Guidelines for the Design and Construction of Small Embankment Dams, p. 6, http://dlnreng.hawaii.gov/dam/wp-content/uploads/sites/9/2013/08/DSGuidelines_R88.pdf

by the soil and water conservation districts and in accordance with an actively pursued comprehensive conservation."

Retention/infiltration structures would need regular monthly inspections as well as periodic inspections following major storm events. In addition, they will require maintenance of the inlet and outlet works. Typical maintenance activities include trash and debris removal, vegetation management, and removal of accumulated sediment. Paid staff would likely need to perform tasks requiring heavy equipment.

Table 6: Sample budget to install one off stream retention basin, assuming minimal excavation is needed due to the use of existing low areas in the floodplain already predisposed to ponding

Item	Cost
Project construction and management	10,000
Design and engineering	5,000
Site survey costs	3,000
General labor (5 days)	5,000
Backhoe equipment rental and operator 5 days	5,000
Contingency costs (15%)	4,200
TOTAL	**$32,200**
Ongoing maintenance (removal of any debris or accumulated sediment) from the inflow and basin following any major storm events. This activity could be accomplished by volunteers	$5,000/year

Monitoring and Evaluation

Monitoring goal 1: a reduction in stream flow related "brown water events" occurring at the mouth of Wahikuli and Honokōwai Streams.

Monitoring and evaluation of high flow diversion performance is best accomplished through direct observation during storm events. Also, in stream monitoring of turbidity and stream flow volumes will be the best indicators of overall function of off stream infiltration/retention structures as well as the presence of absence of brown water exiting the stream mouth into the ocean.

Table 7: Monitoring Metrics

Metric	Methods	Frequency/ Duration	Target(s)
Number of days in which photos show brown water (high turbidity) at	Utilizing methods tested and refined by the West Maui Ridge to Reef Watershed Coordinator, a photo logger will be installed on an adjacent hotel roof that will take a photo each day	Daily once BMPs are implemented and extending to one year beyond the completion date	While this project cannot influence the declaration of brown water days we can use these data to infer how often Wahikuli and Honokōwai streams contribute to brown water

Metric	Methods	Frequency/ Duration	Target(s)
the mouth of Wahikuli and Honokōwai Streams, as correlated with times the stream is flowing	extending to at least one year beyond the project completion to assess stream contribution to turbidity events at the stream mouth. The number of days with 'brown' water will be compared to formally declared 'brown water' days by the County		days and establish a baseline within the timeframe of this project

<u>Discussion</u>

Wahikuli and Honokōwai Streams are classified as intermittent streams. The dry surrounding catchment area and poor infiltration characteristics result in a very "flashy" stream system. Wahikuli and Honokōwai Streams can on some days be completely dry, while on other days they can become raging muddy torrents. Wahikuli Stream flows into the ocean at Honokao'o Beach Park (aka "Canoe Beach"), a 4.6-acre public park that includes a cemetery, beach amenities, and is the base for several outrigger canoe clubs. During periods when Wahikuli Stream is experiencing high flow, muddy nearshore water and swift flowing water prevents the use of these amenities by visitors and residents alike. Depending on the currents and weather, it can be several days before water turbidity clears up and again allows for use of the area. Honokōwai Stream enters the ocean just north of the Aston Resort. Not all nearshore turbidity events at Wahikuli and Honokōwai are associated with stream sediment inputs; wave action and currents causing resuspension of sediment and beach erosion are also causes. Coupling nearshore "brown water" observations with times that the stream is flowing should give an indication of the relative contribution from the stream.

Monitoring goal 2: a reduction in stream flow volume and velocity over time during high flow storm events. The target is a 20 percent reduction over the life of the project

Table 8: Monitoring Metrics

Metric	Methods	Frequency/ Duration	Target(s)
Hydrographic data: (volume and velocity over time)	Calculated from hydrographic data loggers at 2 stream gauging stations in Wahikuli and Honokōwai Streams. These data loggers will collect continuous stream flow volume and turbidity measurement.	Over the duration of the project and 1 year beyond.	20% reduction on peak flow volumes and velocities over time[34]

[34] correlate rain gauge data from gauges in the project area. Stream flow, however, is a proxy of storm events

Discussion

The restoration activities recommended in this report will infiltrate and attenuate significant amounts of stream flow by slowing, filtering, and sinking it into the ground. In theory, this should even out the spikes in the streams' hydrograph, whereby peak flow is delayed, flow volumes are reduced, and velocities become less intense.

Solution 6.b.b: Retention/infiltration Basins (In-stream)

Wahikuli Stream has a minimum of six old road and railroad crossings or earthen 'bridges' with a culvert or tunnel at the bottom to allow stream water to pass through. Many of these structures were hand dug through weaker volcanic strata over 100 years ago, and today they act as constriction points within the stream channel. This is because the volume of water that is able to pass through these structures is inherently limited by the size of the tunnel or culvert. Evidence such as 'trash lines' (accumulated vegetative debris deposited by floodwaters) was observed just upstream of these structures indicating that water does back up against these structures during high flow events (see Figures 19 and 20). These constriction points could be modified to allow for longer retention times and increased water storage capacity (see Figure 21).

Figure 19: Constriction points along Wahikuli Stream, like where the stream flows under this old "Cane Haul Road" could be good locations for in stream retention

Figure 20: Constriction points like this culvert are already limiting flow of the stream. Retrofitting them with grade controls or stand pipes could increase sediment retention effectiveness.

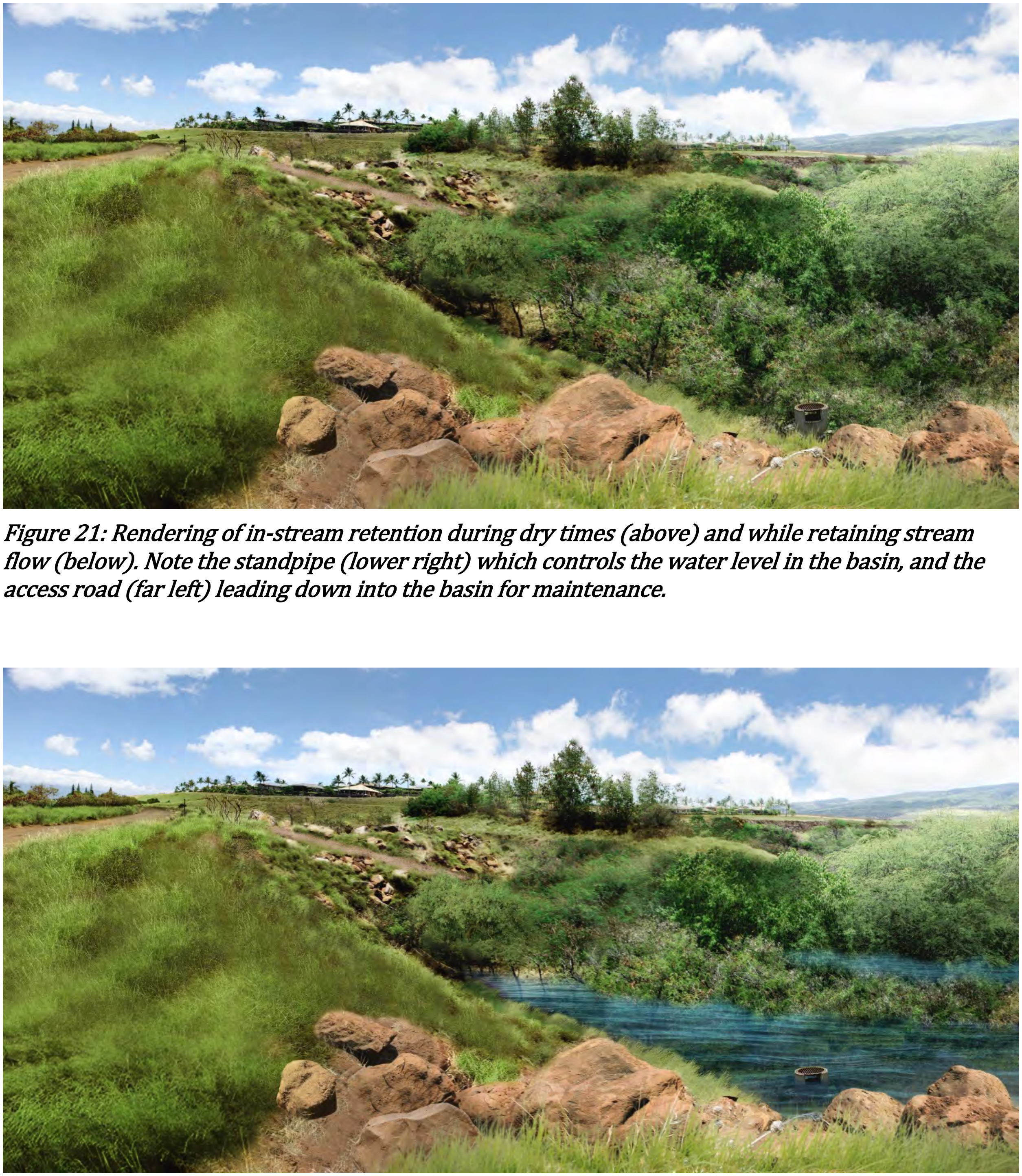


Figure 21: Rendering of in-stream retention during dry times (above) and while retaining stream flow (below). Note the standpipe (lower right) which controls the water level in the basin, and the access road (far left) leading down into the basin for maintenance.

Solution 6c: Multipurpose area with retention (of stormwater), recharge (of groundwater), and recreation (within a community park amenity and open space)

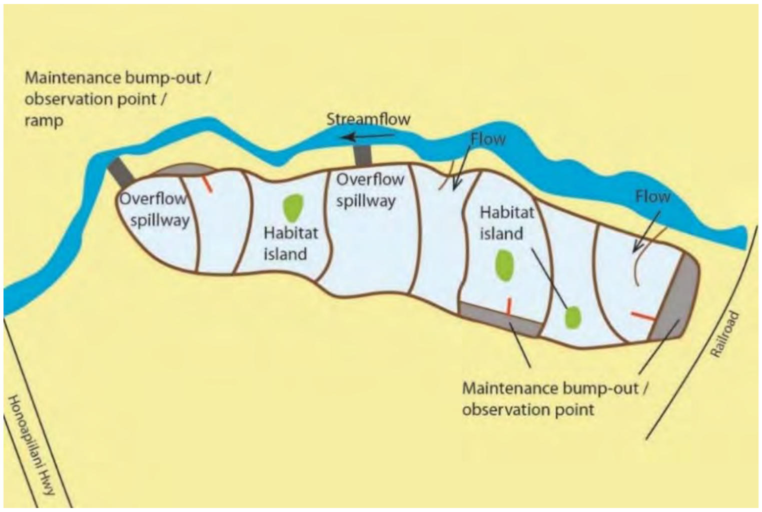
This final restoration recommendation combines all of the aforementioned solutions into a site that accomplishes retention of sediment and stormwater and recharge of groundwater with recreational elements and public use amenities in a park setting. Combining retention, recharge, and recreation enables us to create additional value for local communities, thus increasing the overall benefit, and creating more stakeholders invested in the project's success.

The retention, recharge, and recreation area recommended by the Knowledge Sharing Group is approximately 250 meters (820 feet) long and 50 meters (160 feet) wide, and is located on the Southern riparian stream bank, parallel to Wahikuli Stream. It spans from the old sugar cane train railroad bridge downhill to the Honoapiʻilani Highway. This location was chosen because it is a level floodplain adjacent to Wahikuli Stream, and is located very close to the Kaʻanapali resort area, which includes shopping centers, walking paths, a golf course, and a pedestrian road crossing. The site is well positioned to provide a public use amenity due to its proximity to these population centers of activity, and is large enough (approximately three acres) to provide ample space for storm/stream water retention and infiltration structures.

The retention area will use the site's natural topography, which slopes from approximately 56 feet in elevation near the bridge down to 32 feet by the highway. Preliminary design characteristics divide the park into a stepped-down series of up to eight separate retention/infiltration ponds. Two high flow diversion structures would utilize natural low points in the stream channel to divert stream flow into the first two ponds in the series. As these first ponds fill to capacity, the water would then spill over into the next pond in the series and continue down through the stepped ponds until reaching the last in the series, where the flow would then be directed into additional infiltration structures like wells or trenches, or back into the stream channel. An overflow spillway would provide a failsafe measure for extremely high stream flows (see Figure 22).

The ponds could be maintained as either periodic wet/dry systems or continuous wet systems through the use of supplemental irrigation. Initial discussions with Maui County Department of Water Reclamation indicate that recycled wastewater (R-1 water) could be made available to the site. Wet retention ponds could be designed to function as constructed wetlands and incorporate habitat islands for birds and other wildlife. The design would also include observation areas near ponds that would serve the dual purpose of providing maintenance access for heavy equipment to remove sediment and any other accumulated debris.

There is a need for additional parks and trails in West Maui. Currently the West Maui Community Plan is being revised through a series of public meetings. The public has thus far expressed a strong desire for more parks, sidewalks, and walking/jogging paths in the area, and this is likely to be reflected in the West Maui Community Plan upon its completion in early 2018. The existing ~1.5 mile Kaʻanapali Beach path walkway is used regularly by residents and visitors alike, and accommodates approximately 112,000 walkers and joggers per year. Through use of an existing pedestrian walkway, the southern terminus of this walkway could be extended across the Honoapiʻilani Highway to encompass a circuit of the retention, recharge, and recreation park and provide an additional mauka (away from the ocean/inland) experience for trail users. The trail would terminate at the highest point in the park which affords a sweeping view of the world famous Kaʻanapali resort area.



Figures 22 & 23: Line Drawing (above) and rendering (below) of retention, recharge, and recreation site details indicating flow of stream water into ponds, showing habitat islands, overflow failsafe mechanisms, and observation areas that double as maintenance access points.

Figure 24: Rendering of proposed Retention, Recharge, and Recreation park community amenity.

Walkways and seating areas would be located between the ponds, as well as along the park's perimeter, and landscaping could be used to highlight the unique native plants found in Maui. The park would be planted with native shade trees and plants, and could also include culturally significant food source plants such as avocado, ulu/breadfruit, and mango trees, as well as plants utilized by cultural practitioners such as ʻukiʻuki (tattoo ink), kukui nut (leis and candles), lauhala (weaving mats and canoe sails), and native hibiscus (leis and decoration). A successful recreation area designed to appeal to visitors and residents and highlighting Hawaiian traditions and culture could increase public demand for additional such sites in other locations, potentially unlocking investment from local communities, counties, and businesses. See Figure 24 for a rendering of the recreation area.

The location for the park was chosen because it is a roughly 3-acre parcel next to Wahikuli Stream, contained within the floodplain, and the elevation is roughly equal to that of the stream channel making it relatively simple to direct water out of the channel onto the landscape. It is also well positioned near existing beachfront pathways, golf courses, and a proposed workforce housing neighborhood to create a recreation area that is relatively easy to access by the general public. Also, because it is located within a floodplain, this land is not able to be developed with homes or other structures (Figure 25).

The first high flow diversion leading to the pond system would be located at the upstream end on the left bank (looking downstream) of Wahikuli Gulch to divert flood water into the upstream pond. There would be a second overflow located downstream. There would also be an overflow spillway to act as a failsafe.

Figure 25: Location of retention, recharge and recreation park relative to existing beach path walkway, other parks and population centers.

Table 9: Preliminary installation / construction schedule

Activity:	Year:	1				2				3			
	Quarter:	1	2	3	4	1	2	3	4	1	2	3	4
Preliminary site design and concept renderings complete													
Public outreach and engagement to illicit feedback on proposed design													
Incorporation of stakeholder feedback into design drawings													
Detailed area survey conducted													
Park engineering and design conducted													
Stormwater and recreation park construction													
Ongoing maintenance program through County of Maui, or the Ka'anapali Operators Association (KOA)													

Operation and Maintenance

The Park's retention and recharge elements would require the same or similar maintenance as those listed for each individual component above, with typical maintenance activities including trash and debris removal from basins, aquatic vegetation management within ponds, and removal of accumulated sediment. In addition to these maintenance activities, the park would require regular maintenance associated with other parks like trimming and care of landscape plants, rubbish removal, and cleaning of benches, tables, and other park elements. Ideally, this park could operate as an extension of the Ka'anapali Resort's common areas, and be maintained through an agreement with KOA. KOA is currently responsible for maintenance of the parks and pathways contained within the Resort, and is the likely candidate to conduct ongoing maintenance of the Retention, Recharge, and Recreation Park. An alternative to this arrangement could be an agreement with the County of Maui Department of Parks and Recreation to conduct maintenance activities. The County currently maintains the Park at Hanakao'o Beach Park (also referred to as Canoe Beach).

Estimated Budget

For an estimate of the stormwater elements associated with this solution, see the above referenced retention/infiltration solutions. Park amenity costs are highly variable, and depend upon the extent and type indicated by the intended users. This information will be attained through extensive stakeholder feedback to be conducted in the future, and therefore is beyond the scope of this report.

4. CONCLUSIONS AND NEXT STEPS

This report details a pipeline of shovel ready projects that can be implemented in West Maui. As a next step, CORAL and partners plan to implement a suite of these recommendations in Wahikuli and Honokōwai watersheds. We plan to monitor the effectiveness of these approaches to reduce sedimentation pollution and will develop a report that desribes monitoring results, details implementation plans and lessons learned in order that these efforts can inform the next suite of stream restoration activities in Maui and across the State.

5. ACKNOWLEDGEMENTS

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For more information about these recommendations and restoration activities please contact maui@coral.org