ALTERNATIVE WATERSHED-BASED PLAN FOR THE KAWELA WATERSHED, MOLOKAʻI, HAWAIʻI

Prepared by

The Nature Conservancy of Hawaiʻi
and
the East Molokaʻi Watershed Partnership

for

The State of Hawaiʻi Department of Health

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West fork of Kawela stream

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Abstract

Fencing with continued aerial shooting is the best management approach to reducing sediment on to Kawela's reef. These actions target what are known to be the biggest contributors of sediment loading in the area – feral ungulates and Kawela stream. The EMoWP's use of these methods in the area have already significantly increased vegetation from less than 1% to over 70%, and reduced erosion in USGS study plots from ~6 tons/annually to less than 2 tons/annually, showing their effectiveness. The proposed fencing and ungulate control project is expected to reduce sediment loading to Kawela's reef by 1,521 tons/yr – a 14-fold decrease.

Project Background

To remove feral ungulates and reduce sediment loading on to the reef, the East Molokaʻi Watershed Partnership (EMoWP) is proposing a landscape-level fencing project in Kawela. The proposed project extends fencing from the summit to the lower watershed, protecting 76% of Kawela. United States Geological Survey (USGS) data provide expected lowering rates and sediment reduction with ungulates removed from the fenced areas. Outreach by the EMoWP has brought landowners and key partners together to implement the project.

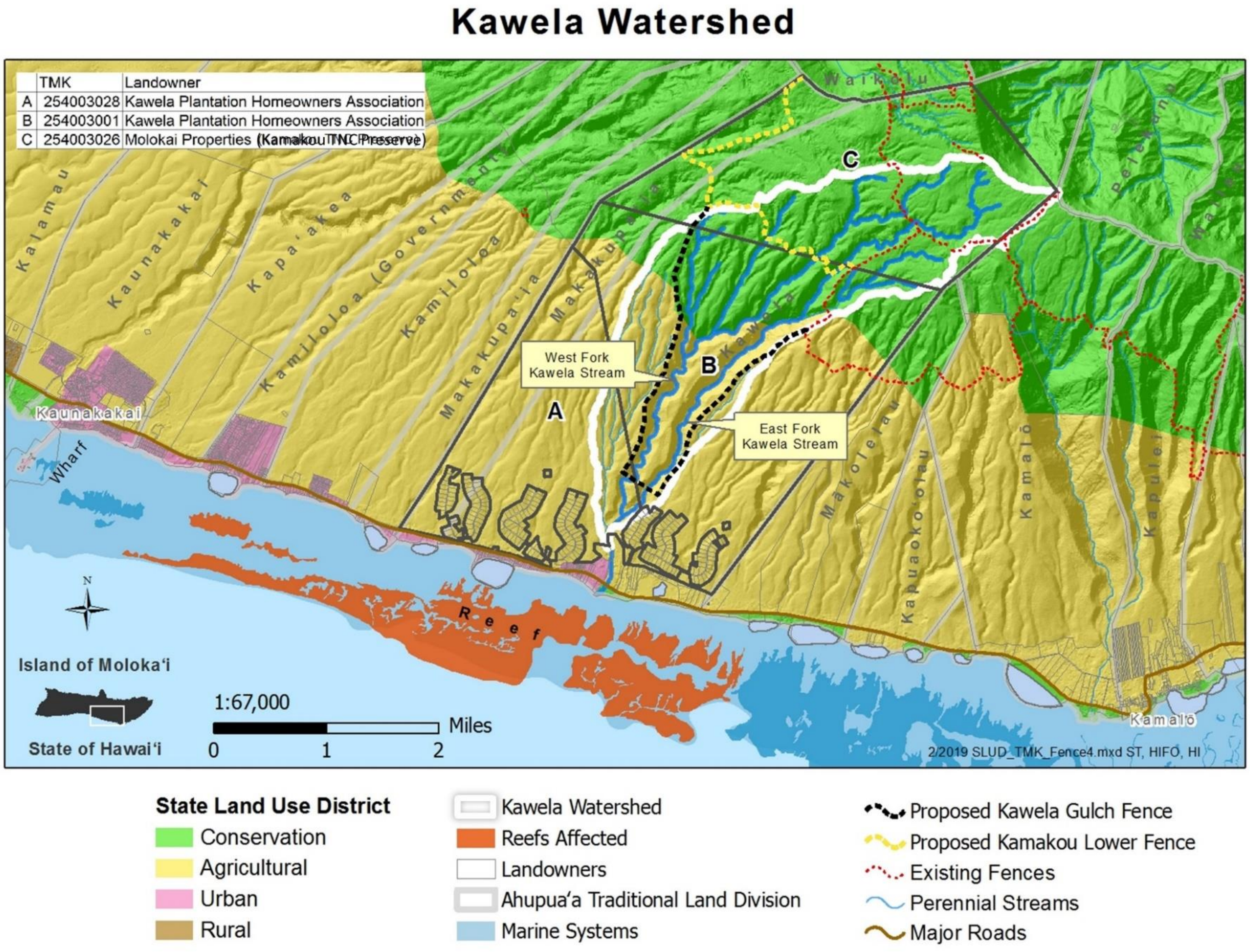
Overview of the Kawela watershed

Kawela lies along the central south coast of the island of Molokaʻi, Hawaiʻi, and encompasses a watershed as well as an ahupuaʻa – a Hawaiian description of landownership extending from the mountains to the ocean (MAP 1, FIG. 1). At 5.3 sq. miles, Kawela is one of the largest watersheds in the East Molokaʻi mountain range. Its central feature is Kawela stream and associated gulch that is made up of east and west forks, which together comprise one of the largest outflows along the island's southern coastline. Kawela literally translates to "the heat" and continues to be known today as hot and desolate.

Native vegetation in Kawela is largely restricted to upper, higher elevation areas, with much of the middle and lower watershed dominated by non-native kiawe woodland with alien grass understory or bare ground (Jacobi 1989, Jacobi and Ambagis 2013, Gon and Tom 2010, USFWS 2015). The high proportion of the watershed covered in alien vegetation and bare ground, particularly in the lower and mid-elevations, is indicative of how much anthropogenic disturbance has occurred in the area.

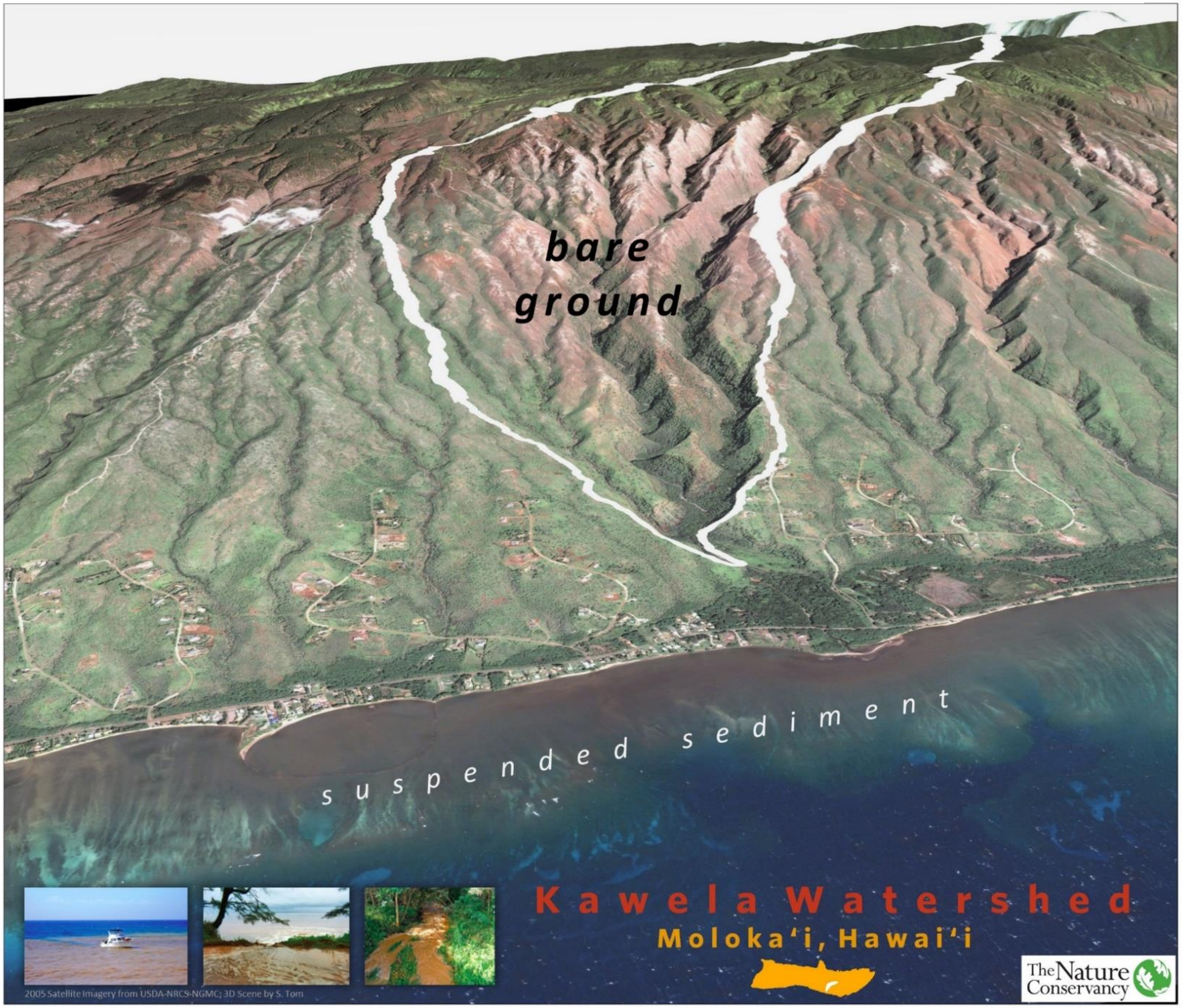
Archaeological research indicates that Kawela was inhabited as early as the 15th century (Weisler and Kirch 1982). As such, Kawela is rich in Hawaiian history and home to a variety of unique cultural resources, including a number of Hawaiian fishponds along the coast as well as many archaeological sites inland, including a puʻuhonua (site of refuge), petroglyphs, and a complete residential complex (1982). In the 1850's, Kawela became part of King Kamehameha V's ranch on Molokaʻi and was used as grazing land for cattle until it was acquired by former Senator Wadsworth Yee and his limited partnership, Kawela Plantation Development Association – the forerunner to the present-day owner, Kawela Plantation Homeowner's Association (KPHA).

MAP 1. Kawela watershed location, landowners, and land use districts.



	TMK	Landowner
A	254003028	Kawela Plantation Homeowners Association
B	254003001	Kawela Plantation Homeowners Association
C	254003026	Molokai Properties (Kamakou TNC Preserve)

Figure 1. Satellite image of Kawela watershed (outlined in white) and neighboring areas (insets are images of the impacts of rain events to Kawela's nearshore environment).



2005 Satellite Imagery from USDA-NRCS-NGMC; 3D Scene by S. Tom

Land ownership

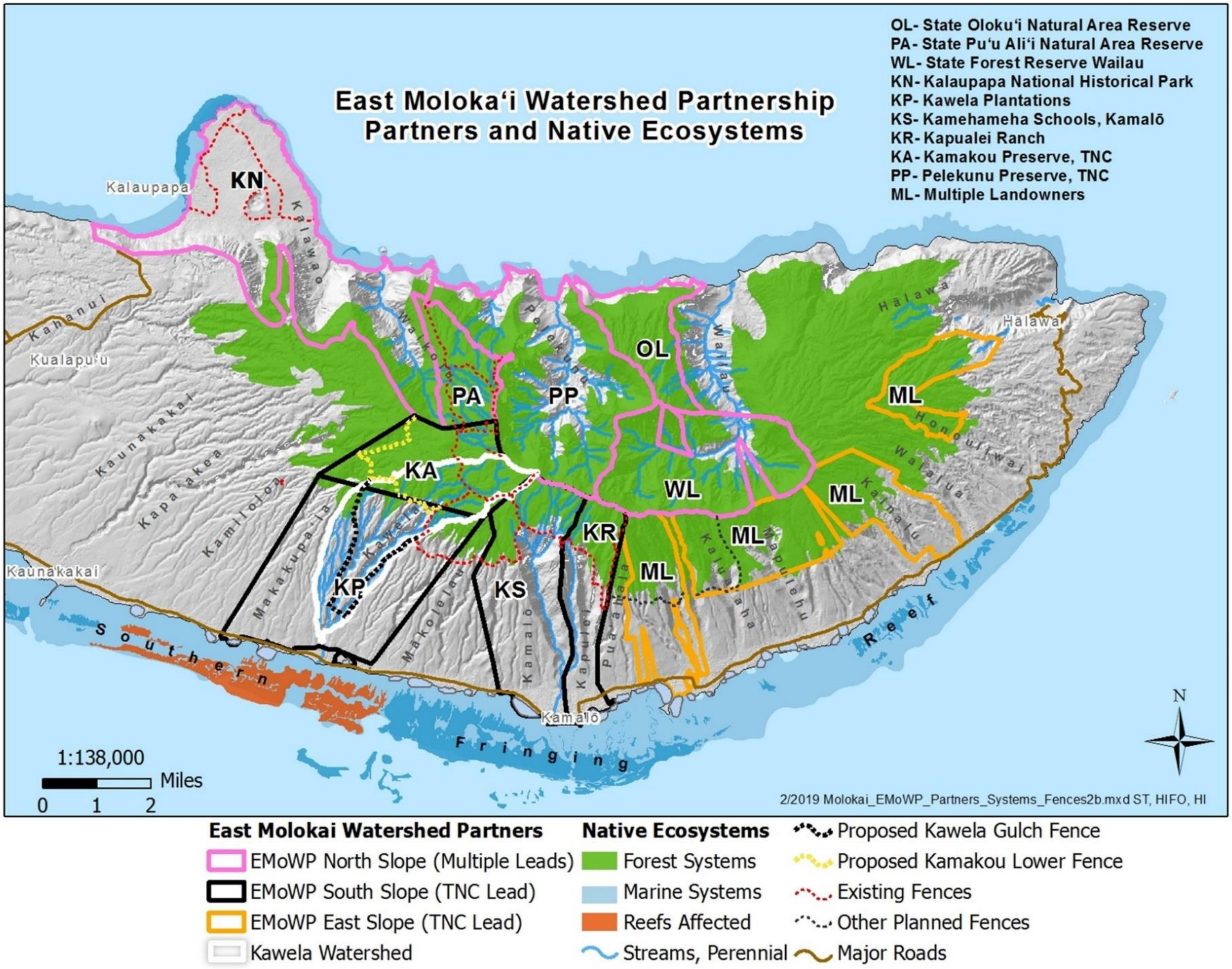
KPHA is residential community made up of homeowners who own 210, two-acre agriculture lots and 5,500 acres of “common ground”. Kawela’s common ground spans from the upper native forest to the coast, including large tracts of mid-elevation bare ground and the 9.3 acre Kaoini Fishpond. There are two large parcels that make up the common grounds, the largest of which is approximately 3,745 acres (TMK 254003001) and extends from 3600 ft. elevation, envelopes homeowner lots, and descends to 200 ft. elevation (MAP 1; parcel B). This parcel’s northern boundary is shared with The Nature Conservancy’s (TNC’s) Kamakou Preserve (TMK 254003026; owned by Molokaʻi Properties). Its southern boundary abuts the ahupuaʻa of Makolelau owned by Alpha Omega Holdings, LLC. The second large common ground parcel is approximately 1,751 acres (TMK 254003028), and spans from approximately 2600 ft. elevation where it descends diagonally to the east to the point above the confluence of Kawela gulch’s east and west forks (MAP 1; parcel A). This parcel’s southern boundary runs along Kamehameha V Highway and east of Kawela stream; it extends north behind Maui County and Molokaʻi Properties Limited; on the west, it is bordered by the Department of Hawaiian Homelands in the ahupuaʻa of Makakupaia.

Terrestrial resources

The Nature Conservancy’s Kamakou Preserve, which sits in the highest elevations of Kawela ahupuaʻa, includes almost 3,000 acres of intact, native rainforest (MAP 1). Kamakou was the Conservancy’s first Hawaiʻi preserve acquired in 1982, and remains a biological icon, extending down the Molokaʻi upland from an elevation of near 4,500 feet to roughly 3,600 where it abuts KPHA’s common ground. More than 200 species of native plants provide habitat for tree snails, happy-face spiders and forest birds like ʻapapane (*Himatione sanguinea*) and ʻamakihi (*Hemignathus virens*). There are two major native vegetation types that occur in good health in Kawela: 1) ʻōhi’a (*Metrosideros* sp.) montane wet forest; and 2) ʻōhi’a montane mesic forest and shrubland (Jacobi 1989 and 2013, Gon and Tom 2010, USFWS 2015). Although greatly impacted, other native vegetation types that occur in the area are lowland dry forest and shrubland and lowland mesic forest and shrubland, typically dominated by ʻaʻaliʻi (*Dodonea viscosa*), ʻilima (*Sida fallax*) and mixed grass species. Most rare species occurring in the area exist above 2600 ft. elevation and within montane wet and montane mesic forest types. There are 30 federally listed endangered plant species, five candidates for listing and 19 species of concern in Kawela and adjacent ahupuaʻa that together make up the EMoWP’s South Slope management area (MAP 2; USFWS 2015).

The EMoWP is a collaboration of 22 public and private partners who work to protect over 45,000 acres of native watershed forests on the island (TNC 2015). The EMoWP is coordinated by TNC’s Molokaʻi Program. Created in 1999, the EMoWP’s first project was the construction of a 5.5 mile watershed protection fence stretching from Kawela to Kamalō for the purpose of reducing feral ungulate (hooved animal) impacts, restoring vegetation and reducing erosion and sediment on to the reef. Since this time, the EMoWP has expanded its conservation footprint

MAP 2. East Molokai Watershed Partnership partners, management areas and native ecosystems.



across the island by creating and working in the North Slope and East Slope management areas (MAP 2).

Marine resources

Makai (sea ward) of Kawela's upland resources lies a portion of the Molokaʻi South Shore fringing reef system. This reef system is considered the longest, continuous fringing reef in the United States, extending approximately 30 miles along the island's southern coastline, and has been characterized as one of the best examples of coral ecosystems in the State of Hawaiʻi (Field et al. 2008a). Kawela's reefs are a significant food source for the Kawela Plantation Homestead Association's residential community, as well as adjacent residents in the ahupuaʻa.

Kawela's nearshore waters are included within the 303(d) list of total suspended solids (TSS)- and turbidity-impaired waters "South Molokai Coast-nearshore waters to 18' from SW point-Waialua HIW00052" (State of Hawaiʻi 2018). This designation extends from the southwest point of the island to Waialua, to 18' depth. Long-term TSS data at the mouth of Kawela stream (USGS Pacific Water Science Center) indicate that storms bring tons of sediment to the reef. The sediment discharging into nearshore waters from Kawela watershed averaged 1,345 tons/sq. mile annually from 2006-2011 when growing feral goat and deer populations destroyed the middle elevations' soil cover.

After significant efforts by the EMoWP to reduce goat populations began in 2009, a dramatic decrease of sediment discharge followed, as seen in the 2016-2018 average of 348 tons/sq. mile annually in a temporary fashion [figure has been corrected for only partial data in 2016 wateryear. All annual data is reported by wateryear (October-September)]. Without active continuing management of the impacts of feral goat and deer populations in this area, these high-quality waters will become highly impaired again.

Coral reef researchers from the USGS also monitored coastal waters for sediment composition and turbidity for five years at the beginning of the goat reduction efforts (Brown et al. 2008, Field et al. 2008b). Land-derived sediment is trapped on the inner reef flat and resuspended by swell and wind. There can be up to 15cm of fine terrestrially-derived sediment on the inner reef flat in some places. Sediment impacts reef health and survivorship by blocking light needed for photosynthesis, limiting recruitment sites, smothering new coral settlements and encrusting corals, and can even bury large coral colonies which are killed. It is likely that because of poor flushing rates, fine sediments can be trapped for up to decades.

<u>Threats to Kawela's Coral Reef Ecosystems</u>

Feral ungulates and erosion

As a result of centuries of feral ungulate impacts, Kawela is a barren landscape (FIG. 1 and 2). Beginning with cattle in the 1850's, ungulates have significantly impacted the native forest and shrubland ecosystems in the ahupuaʻa and are the primary reason why these vegetation types are virtually non-existent today in the lower, dryer reaches of Kawela. While the last cattle were removed from the island in the 1970’s, today, feral goats (*Capra hircus*), axis deer (*Axis axis*), and pigs (*Sus scrofa*) pose the greatest threat to native ecosystems in the area.

Figure 2. Fence effects inside and outside EMoWP watershed fencing in Kawela.

Goats roam in large numbers, are free from natural predators and inhabit the steepest terrain as their safe haven. Consequently, they strip the landscape of vegetation, which results in increased lowering rates and diminished infiltration capacity of the watershed (Stock et al. 2011, Jacobi and Stock 2013, 2017). Axis deer, while more elusive than goats, have seen population explosions on island over the last two decades with consequent and substantial impacts to natural areas due to browsing impacts. Feral pigs are found in all elevations and easily adapt to the wettest, highest elevations where they dig up understory vegetation exposing bare ground to run off and invasive weed invasions. In Kawela, during dry, hot times of the year, goats and axis deer herds move to the upper montane mesic and wet forests where they graze on the forest edge or “browse line”. The area below the browse line is a remnant dying forest, as evident by the mix of native dead tree stumps and invading alien grass. Below these dying forest grasslands, the landscape becomes a sea of alien vegetation, red dirt and gray rock (FIG. 1 and 2).

For decades, Kawela’s steep, barren lands have been eroding at rates 100 times more than historic averages, depositing fine silts and sediment that pollute the island’s reefs (Field et al. 2008b, Stock et al. 2011, 2016). In response to this high rate of erosion and its significant downslope impacts to coral reefs in the area, scientists from the USGS collaborated with TNC and the EMoWP to better understand the sources and impacts of sediments, nutrients and pollutants in the area. Known as the Ridge-to-Reef or R2R project, this study’s driving questions focused on understanding the relationship between feral ungulate populations (largely goats), vegetation, and sediment transport in the area. Fencing, ungulate control, monitoring changes in plant species composition and cover, as well as documenting water runoff, sediment generation, and sediment transport in sampling areas both inside and outside fences, in addition to mapping and collecting data across the entire watershed led to a number of key findings.

Primarily, this work found that feral ungulates are the primary reason for the degradation and denuding of the Kawela watershed; that grazing impacts caused by feral ungulates are responsible for increased erosion rates in the Kawela watershed; and, that this upslope erosion has resulted in sedimentation of the near shore fringing reef (FIG. 3; Field et al. 2008b, Stock et al. 2011, 2016, Jacobi and Ambagis 2013, Jacobi and Stock 2013, 2017). Furthermore, USGS data shows that Kawela’s high value coral reefs are being disproportionately impacted by erosion from the Kawela watershed via Kawela stream, whose east and west forks connect approximately 400 meters from the coast and together contribute the greatest outflow of sediment from the Kawela watershed (Stock et al. 2016).

Stakeholders also agree that suspended solids threatening Kawela reef are caused by large populations of feral ungulates and that coral cover is declining in the region (State of Hawai‘i et al. 2004). The State of Hawai‘i’s 30 x 30 commitment to nearshore reef protection (30% protected by 2030) asserts the need to effectively manage the local stressors that are within our control, including sediment and nutrient runoff from land and invasive species (State of Hawai‘i 2016).

Connecting feral ungulates and erosion to impacts on the coral reef

The sedimentation of Moloka‘i reefs is demonstrably chronic. TSS and Turbidity have impaired these coastal waters, likely since the introduction of cattle in the 19th century (State of Hawai‘i 2004). Turbidity levels have been recorded that are far higher than the commonly accepted 10 mg/L concentration known to negatively impact corals established by Rogers in 1990. Turbidity levels near Kawela were recorded as high as 79 mg/L at 50 m from shore, and 33 mg/L at 100 m from shore (Field et al. 2008b). This corresponds with low coral cover in the adjoining reef. Associated declines in juvenile recruitment of dominant corals were also documented over five years (Brown et al. 2008).

Over the last decade, efforts by TNC and the EMoWP have dramatically reduced feral ungulate numbers in the area, allowing large portions of the landscape to revegetate. Vegetation monitoring by Jacobi and Stock found that in representative sites, vegetation cover increased from less than 1% to over 70% in a five-year period spanning from 2008 - 2013 (FIG. 3 and 4; 2017). By controlling ungulate numbers, areas were largely released from browsing pressure, and plants that were previously unable to grow were now able to grow more abundantly resulting in a dramatic increase in vegetation (2017).

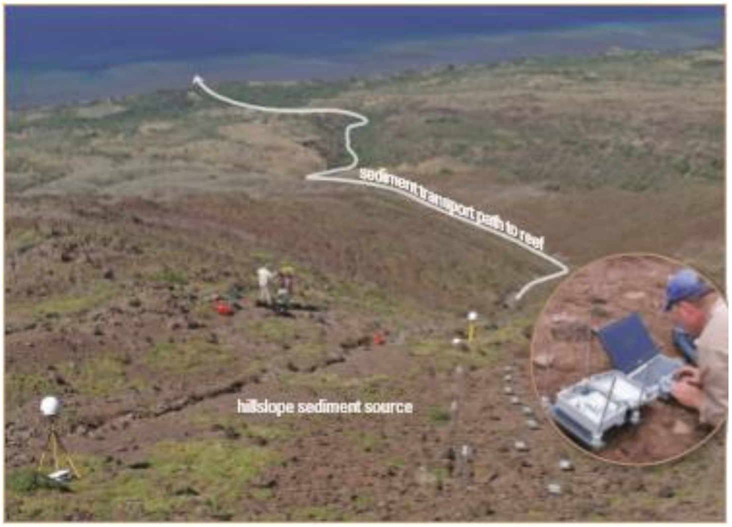


Figure 3. Taken from Stock et al. 2011 showing USGS Ridge to Reef study site in Kawela, Moloka‘i.

USGS research findings also show that these vegetation increases meant that hillslope sites that were previously bare soil and supplied the watershed with fine silts and muds, were now covered with vegetation, litter and thin deposits effectively shutting down erosion as they revegetate (Jacobi and Stock 2013). At experimental study sites in Kawela where USGS had documented

Figure 4. USGS Kawela ridge plot site in 2008 and 2014.

0.4 inches/year of soil erosion for a period of five years, a 10-fold reduction in erosion rates was measured because of revegetation (FIG. 3; 2013).

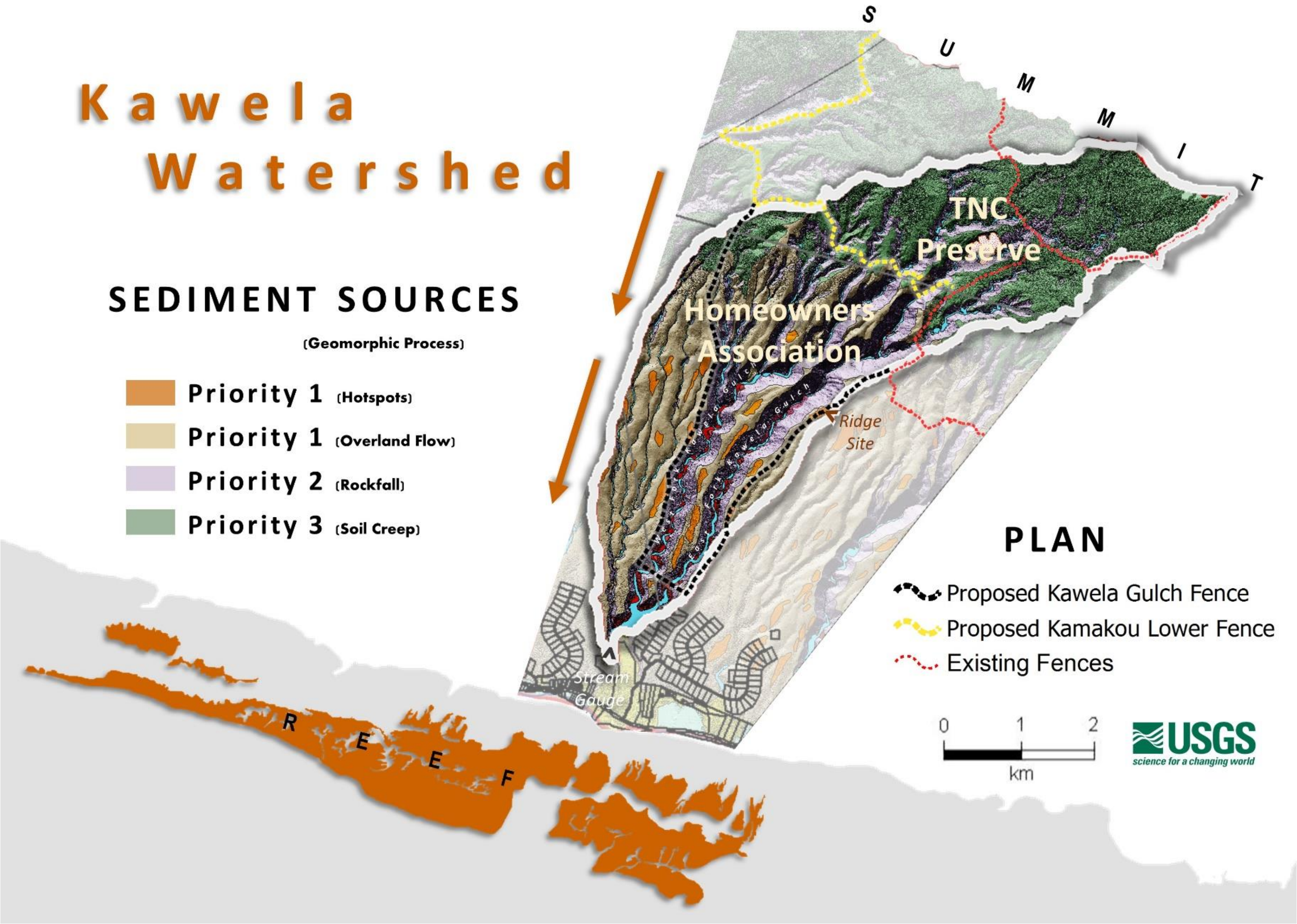
USGS data from the R2R project also identified that the majority of fine sediment eroding from the Kawela area comes from the geomorphic processes of overland flow and hotspots (MAP 3; Stock et al. 2011, Jacobi and Stock 2013). These priority erosion control areas were historically vegetated but have been denuded by unsustainable ungulate browsing pressure (Jacobi and Stock 2013, 2017). Research has found that while the hotspots make up only 2.5% of the watershed area, they contribute to the excess 40% sediment export from non-natural sources (2013, 2017). This excess 40% of sediment is controllable to baseline erosion through a single action – removing ungulates. With ungulates removed from the landscape, USGS data estimates that hotspot erosion will be reduced from 1.4 cm/year to 0.1 cm/year (Stock et al. 2016). The remaining 60% of sediment export has been proposed to mainly originate from overland erosion processes. It is expected that these processes will also be reduced to natural rates by removing ungulates.

Project Description

Fencing with continued aerial shooting is the best management approach to reducing sediment on to Kawela's reef. Currently, fencing in Kawela is restricted to the Upper Kamakou fence in the most mauka reaches of the ahupuaʻa and the Kawela Subunit fence, which lies below the Upper Kamakou fence and to the east of Kawela gulch's east fork (MAP 3). The vast majority of the ahupuaʻa is unfenced. Standard animal control techniques such as ground hunt sweeps utilizing hunters and dogs are ineffective in unfenced areas, which has restricted animal control in Kawela's middle and lower elevation areas to aerial shooting.

Aerial shooting is a method of animal control whereby feral ungulates are located and dispatched from a helicopter. Aerial shooting missions in the EMoWP's South Slope (including Kawela) occur three times per year, are coordinated and funded by the EMoWP, and implemented by the State of Hawaiʻi Department of Land and Natural Resources (DLNR). While an important and effective animal control tool, aerial shooting has its limitations and vulnerabilities, particularly in unfenced areas such as Kawela. The method's high cost and high risk have made it unavailable in the past, and EMoWP aerial shooting data show that ungulate populations can rebound over very short timeframes (EMoWP 2019). It is also a contentious method of animal control and often requires considerable and consistent stakeholder engagement. Additionally, aerial shooting in unfenced areas will never get the ungulate population to zero, and will, therefore, always allow some level of ungulate presence to persist, and consequently, increased sedimentation to remain. Recent EMoWP data supports this claim, showing that the number of animals dispatched per aerial shooting mission has plateaued suggesting that the size of the ungulate population in the area has reached a stasis (2019). Aerial shooting used in concert with fencing would allow all ungulates to be removed from within the fenced areas, thereby effectively shutting down erosion.

MAP 3. Kawela watershed sediment sources and proposed fences.



Proposed fence units

The proposed fencing project in Kawela includes two fenced units – an upper unit referred to as the Lower Kamakou fence and a lower unit called the Kawela Gulch fence (MAP 3). The two units are necessary to effectively address water quality problems in the Kawela watershed. The Lower Kawela fence is approximately 4.5 miles and encompasses roughly 1,260 acres, while the Kawela Gulch fence is approximately 5.1 miles, encompassing 1,320 acres. Consolidating these units into one would make ungulate management within them extremely challenging given the large size of a single unit and differences in terrain, vegetation cover, and available management techniques. Implementing this project as two fence units - Lower Kamakou and Kawela Gulch - will effectively address hotspot and hillslope erosion in the Kawela watershed and restore riparian buffer zones along Kawela stream. Together, these fences will address water quality problems in Kawela by protecting an additional 55% of the Kawela watershed. In combination with existing EMoWP fencing in the area, they will protect 76% of the Kawela watershed.

Project cost estimates

Funding for the 4.5 mile Lower Kamakou fence section was requested by the DLNR in their FY20-21 Watershed CIP budget request to the state legislature. This request was fully awarded for $900,169. Funding for the Kawela Gulch fence section will be requested from the State of Hawaiʻi Department of Health 319 funds upon approval of this alternative watershed plan. The cost estimate of the 5.1 mile Kawela Gulch fence is $1,031,000. This cost estimate is based on the Lower Kamakou fence cost estimate as well as the costs of recently completed EMoWP fences in Upper Kamakou and Waiahoʻokalo. The Kawela Gulch fence cost estimate includes fence construction ($1,020,192) and initial ungulate control ($10,800); it does not include long-term maintenance costs of the fence, which despite the EMoWP's diverse funding stream, remains a consistent challenge.

Initial ungulate control within the Kawela Gulch fence will be done via aerial shooting. It is estimated that six aerial shoot missions done once, every other month will achieve zero tolerance or very near it within the first year. Aerial missions are estimated to take approximately one hour, at $1,200/hr., for a total of $7,200 in year one. It is estimated that year two will require three missions, evenly spaced, for a total of $3,600. Following year two, annual aerial missions will survey the area three times a year during scheduled aerial shoot missions in the EMoWP's South Slope management area. These survey missions don't require funding as they are already within the EMoWP's budget.

Project implementation

Estimated fence construction implementation and ungulate control milestone deliverables, schedule and team are outlined in Table 1. Construction of the Lower Kamakou fence will precede construction of the Kawela Gulch fence. Fence surveys for the Lower Kamakou fence are near completion, and compliance has been completed with the State of Hawaiʻi Office of

Table 1. Estimated fence construction and ungulate control implementation schedule and team.

Deliverable	Team	FY20 1st	FY20 2nd	FY20 3rd	FY20 4th	FY21 1st	FY21 2nd	FY21 3rd	FY21 4th	FY22 1st	FY22 2nd	FY22 3rd	FY22 4th	FY23 1st	FY23 2nd	FY23 3rd	FY23 4th	FY24 1st	FY24 2nd
Lower Kamakou fence survey	EMoWP	🟦	🟦	🟦	🟦														
Lower Kamakou fence compliance	DOFAW TNC	🟦	🟦																
Lower Kamakou fence construction	DOFAW							🟦	🟦	🟦									
Lower Kamakou ungulate control*	EMoWP									🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Kawela Gulch fence survey	EMoWP										🟦	🟦	🟦						
Kawela Gulch fence compliance	DOFAW TNC										🟦	🟦							
Kawela Gulch fence construction	DOFAW															🟦	🟦	🟦	🟦
Kawela Gulch ungulate control*	EMoWP																		🟦

* Ungulate control will need to occur over the course of many years to achieve and maintain zero tolerance in fenced units.

Conservation and Coastal Lands providing a Site Plan Approval (SPA) on October 15, 2019. Construction of the Lower Kamakou fence is estimated to begin in the third quarter of FY21 and is estimated to take 6-8 months to complete. Depending on funding, compliance and fence survey deliverables for the Kawela Gulch fence section are estimated to start towards the end of the Lower Kamakou fence construction, with construction of the Kawela Gulch fence not estimated to begin until the third quarter of FY23. While the proposed fencing and ungulate control actions are critical to addressing water quality problems in the Kawela watershed, TNC and the EMoWP cannot commit to the Kawela Gulch fence section of this plan without 319 funds.

Post-fence construction cost-sharing will include funding from entities that consistently fund the EMoWP including but not limited to, Maui County Department of Water Supply, State of Hawaiʻi Watershed Partnership Program, Kamehameha Schools Bishop Estate, and The Nature Conservancy.

Improved Water Quality

Water quality overview

The proposed ungulate removal is anticipated to improve water quality through subsequent vegetation regrowth and erosion reduction. Via a concerted effort over the last 15 years, TNC and EMoWP demonstrated that more than 5,000 tons of sediment per year from Kawela watershed can be prevented from entering the nearshore waters, as measured by the USGS gauge at the base of the watershed, following ahupuaʻa-wide revegetation due to ungulate control. Sediment export from Kawela ahupuaʻa dropped dramatically from an average of 7,100 tons to 1,850 tons annually between 2006-11 and 2016-2018 (USGS National Water Information System 2019).

As previously mentioned, removing ungulates from within the proposed fences is expected to reduce sediment loading to the reef by 1,521 tons/yr – a 14-fold decrease. Sediment export was calculated from 1,638 tons/yr with ungulates versus 117 tons/yr without ungulates based on Stock et al.'s lowering rates of 1.4cm/yr with ungulates compared with 0.1cm/yr without ungulates (2016). However, the effects of the proposed actions on sediment export are believed to be much greater given that sediment retention by the riparian barrier into Kawela gulch is not accounted for in this sediment reduction estimate.

Without a continued excess sediment source, the reef will continue to flush out the sediments entrained in the nearshore waters. In particular, we anticipate storm events to be less impactful for the downstream reef. Individual storms in 2016-2018 (after revegetation) generated stormwaters with only 26% of the suspended sediment concentration seen in 2006-2011(42 vs 165 mg/L; USGS National Water Information System 2019). This reduction has been noticed by Molokaʻi residents who observed that the color of Kawela stream was a lighter brown tea color in 2016-2018 versus the darker opaque brown seen in the previous decade (E Misaki pers comm, 1/12/2018). Increased vegetation and ground cover slows water down and increases infiltration.

We expect a reduction in coastal turbidity within a multi-year to decadal time scale, similar to reductions in turbidity that have already been observed. The percent reduction is related to the amount of rainfall, which allows for vegetative regrowth in previously degraded areas. Subsequently, we expect a reduction in coral mortality and increase in coral cover – depending on complicated ecosystem conditions, including water temperatures and herbivore densities.

The proposed fencing and ungulate control actions will address water quality problems in Kawela watershed, resulting in the protection of an additional approximately 55% of the Kawela watershed. In combination with existing EMoWP fencing, will collectively protect approximately 76% of the Kawela watershed. USGS data show that native vegetation will return on the protected watershed.

Maintenance best management practices (BMPS) are expected to help control the remaining sediment sources not included with the proposed fences. Maintenance BMPS include continued aerial shooting and the creation of a riparian buffer along Kawela stream via the Kawela Gulch fence. Riparian buffers are well-established BMPS for sediment retention and water quality improvement by catching sediment that comes from neighboring/adjacent hotspot and hillslope areas (Anbumozhi et al. 2005, Liu et al. 2008).

Water quality monitoring approach

Water quality monitoring is currently in place to determine water quality trends resulting from the proposed work, including data collected by the USGS Pacific Water Science Center and the Hawaiʻi State Department of Health.

Stream height and suspended sediment concentration will be monitored at USGS Kawela Stream Gauge site (Site number 164156000) using pressure sensors and automatic sediment samplers, located in the lower reaches of Kawela stream (MAP 3; FIG. 5). Historic ratings curves will be used to estimate stream discharge. Suspended sediment concentration curves will be used to

Figure 5. Kawela stream gauge with ISCO automated water sampler and pressure sensor.

estimate suspended sediment concentration and loading. The site has been in operation since 2005, and is in current operation, with a total of nearly 4000 days of samples. However, between 2011 and 2015 the gauge was inactive. EMoWP worked with USGS and in 2016 received Maui County Department of Water Supply funding to pay operating costs. The station includes an ISCO automated water sampler, and a pressure sensor to measure water depth, as seen below.

In addition, we hope to replicate the sediment trap deployment and monitoring that was conducted in 2008 in the nearshore coastal waters adjacent to Kawela to estimate if changes in stream sediment load are reducing sediment in the coastal water column. This will be a collaboration with the USGS Coastal team from University of California at Santa Cruz to learn previous locations for sediment traps, and their exact geometries. This would be a separate funding request to NOAA or other agency at a later date.

DOH CWB recently identified two sampling sites in Kawela to begin regular coastal water quality sampling on a regular basis under the BEACH program: one 0.3 miles west of the stream mouth and another at the stream mouth. Monthly field measurements for temperature, salinity, dissolved oxygen, pH and turbidity will be conducted and water samples will be collected to analyze for ammonia nitrogen, nitrate + nitrite, total nitrogen, total phosphorus, and chlorphyll-a. Data is publicly available through the HDOH website, and the WQX database maintained by the EPA.

Coral monitoring approach

Coral reef tract surveys were conducted last in 2007, at two transects east and west of Kawela in Kamiloloa and past Kamalō (Field et al. 2019). The last time the bathymetry was conducted in Kawela, the inner reef lagoon was less than 5m in many places. Future surveys, funded separately, would repeat the coral transects to the west and east of Kawela, and add an additional transect at the mouth of Kawela stream (see FIG. 6 below from Field et al. 2019, showing the two nearest transects). Benthic communities will be assessed by taking photographs of the benthos along the same transect lines previously conducted and analyzing those photographs for percent composition of the benthic community, including corals by species. Using external funds, additional monitoring could update the dataset, including coral health and fish surveys.

Changes in the coral reef community are anticipated on a 5-10 year time scale, and it would be advisable to survey the reef every 5 years to document changes in community composition, structure and percent cover.

Stakeholder and Key Partner Participation

Key partners and stakeholders are in place to implement this plan. The Board of Directors of KPHA have provided a letter of support, documenting their commitment to this plan and to watershed protection in Kawela ahupuaʻa (Appendix 1). KPHA is also in the process of updating

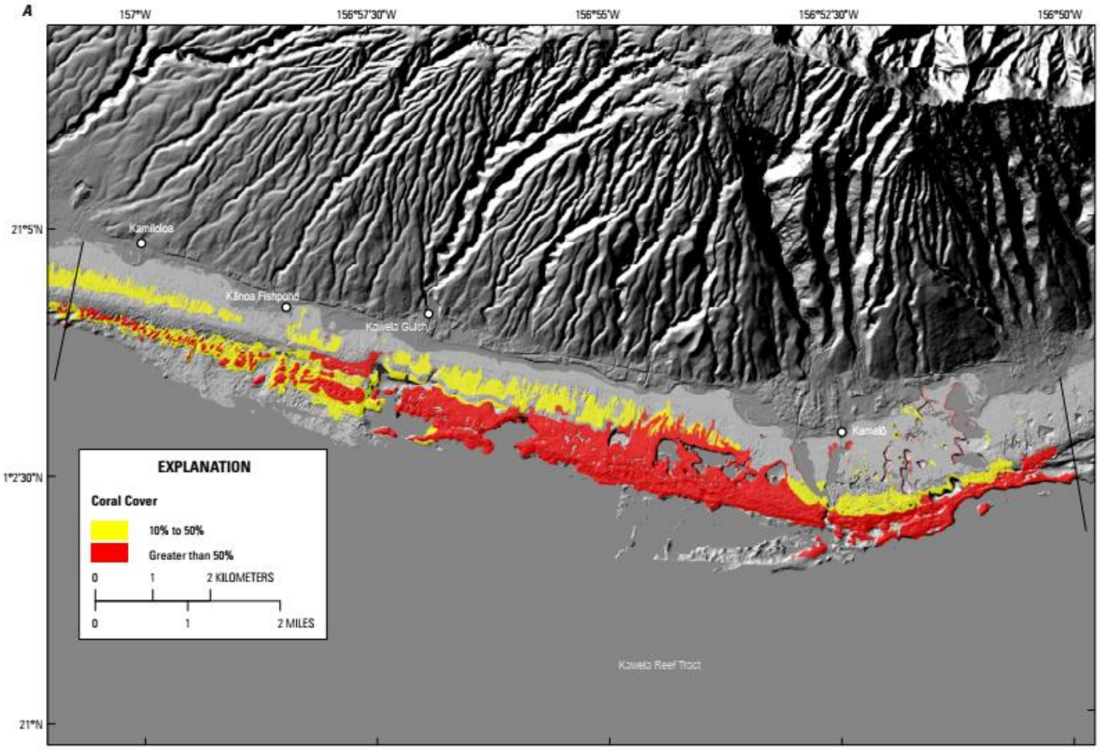


Figure 6. Figure from USGS (2019) showing major reef coral cover and transect lines (black) to the east and west of Kawela gulch.

their watershed management plan and has made clear they do not intend to significantly develop their lands in the future (KPHA 2012). Additionally, KPHA has a management Right of Entry with the EMoWP, outlining access agreements for land management activities on KPHA property. The Conservancy and EMoWP have met several times with KPHA's Board to discuss the proposed project, including a site visit to the proposed Lower Kamakou and Kawela Gulch fence areas.

Through the course of this planning effort, KPHA, TNC and the EMoWP have shared this project with community groups active in the area, providing project details as well as asking for feedback. Multiple meetings and a site visit took place with the Kawela moku of the ʻAha Kiole ʻo Molokaʻi to introduce and discuss the project. The ʻAha Kiole ʻo Molokaʻi is part of the statewide ʻAha Moku system structured within DLNR to advise on Hawaiian traditional land and ocean practices. It is the EMoWP's standard practice to engage the regional moku representatives of the ʻAha Kiole ʻo Molokaʻi in areas where EMoWP projects are taking place or proposed. Interactions with the Kawela moku representatives about the project indicate they are supportive of this plan and its goal of reducing sediment to the reef.

Additional stakeholders were also engaged. Ka Honua Momona is a local non-profit, located along the coastline, downwind of Kawela stream's outflow in adjacent Makakupaia ahupuaʻa. The organization's focus on sustainability and dedication to fishpond revitalization has made them keenly interested in and supportive of this plan's efforts to reduce sedimentation on to the reef. The EMoWP have also included DLNR-DOFAW in project discussions. Agency staff have participated in fence route surveys to identify the best fence alignment for the Lower Kamakou fence. It is anticipated that agency staff will also participate in ground surveys for the Kawela Gulch fence. The EMoWP has also shared the project with the Game Management Advisory Commission (GMAC), which serves in an advisory capacity to the Board of Land and Natural Resources (BLNR) on issues related to hunting. Communications from the Chair of GMAC, Lori Buchanan, were supportive of this effort. On an individual basis, the EMoWP has reached out to KPHA homeowners who actively hunt in the common grounds of the ahupuaʻa, and their comments have helped shape this plan.

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Appendix 1

Kawela Plantation Homeowner’s Association Letter of Support

KAWELA PLANTATION HOMEOWNERS' ASSOCIATION
Post Office Box 28 Kaunakakai, Hawaii 96748
Phone: (808) 553-4223 Fax: (808) 553-3996
E-Mail: kawelapha@gmail.com www.kawelapha.com

December 9, 2019

To Whom It May Concern,

At the request of Yvonne Everhart, Kawela Plantation Homeowners' Association (KPHA) Board of Directors President, I am writing this letter to acknowledge that the Board of Directors for KPHA fully supports The Nature Conservancy and East Molokai Watershed Partnership's Alternative Watershed Plan for Kawela Plantation. As well, the Board of Directors shares that a majority of Kawela Plantation's 210 landowners appreciate, understand and support the important work The Nature Conservancy and East Molokai Watershed Partnership will carry out, helping the common lands revegetate and sediment on the reef reduced.

With the exception of a moderate solar field area (1.6 acres) to be located between the KPHA office and existing water tank in Unit II at the top of Uluanui Road in Kawela Plantation, KPHA has no plans to develop the common ground lands which The Nature Conservancy and East Molokai Watershed Partnership will use to do their work of protecting and helping the land.

Kawela Plantation Homeowners Association and our Board of Directors recognize all the varying factors that lead to the destruction of vegetation, erosion and sediment transport and appreciate all that The Nature Conservancy and East Molokai Watershed Partnership are doing for Kawela and Molokai. Thank you for your time.

Sincerely,

Maureen Whittemore
KPHA Administrative Manager

APPENDIX 2. ADDENDUM TO THE ALTERNATIVE WATERSHED-BASED PLAN FOR THE KAWELA WATERSHED, MOLOKA’I, HAWAI’I

August 2025

Estimating Pollutant Load Reductions Resulting from Control and Removal of Invasive Plant and Animal Species and Establishment of Native Species

Introduction

This addendum has been developed by the Hawaii Department of Health (HDOH) to address additional considerations and updates relevant to watershed management efforts. This addendum supplements the Alternative Watershed-Based Plan for the Kawela Watershed, Moloka'i, Hawai'i to include activities and additional guidance related to the removal of invasive plants and animals, as well as the reintroduction of native species. In addition to including these activities in the menu of best management practices (BMPs) that are eligible for 319 funding, this addendum provides an approach for calculating the pollutant reductions associated with these restoration activities. These pollutant reductions can be used by project managers and sub-grantees to develop individual project plans and by HDOH to calculate annual pollutant reductions for the broader NPS program.

Pollutant Loading from Invasive Species

Invasive plants and animals are an increasingly challenging source of pollution in many of Hawaii's watersheds. Invasive plants, such as miconia, have shallow root systems, which are unable to stabilize the soil and are susceptible to erosion and landslides during rainfall events. Invasive animals, such as feral hogs, are destructive grazers, uprooting plant material and exposing additional areas to erosion.

As a result, sediment is the primary pollutant of concern from invasive species, although other pollutants may also be transported during rainfall events (e.g., nutrients and bacteria). Sediment has been identified by HDOH as a pollutant of concern across the state and is a focus of water quality improvement efforts. This watershed-based plan already includes a discussion of pollutants of concern and the load reductions needed to return the impaired waters to attainment. This addendum supplements that discussion; invasive species are one of multiple pollutant sources to be addressed.

Pollution Control Practices

Across Hawaii, many organizations (including federal, state and local government, as well as watershed groups) are working to mitigate these problems. In many cases, this involves removing the invasive species and replacing them with native species. Native plant species[1] are better adapted to the soils and climate and provide improved soil retention, among other benefits. Excluding invasive animals, such as using fencing to block access to an area, allows vegetation to recover and thrive.

Table 1 below includes BMPs that can address pollutant loading caused by invasive species.[2] As shown by the large number of potential BMPs, vegetative plantings are a common element of

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[1] See, for example, https://dlnr.hawaii.gov/forestry/plants/ for a discussion of native plant species.

[2] The table shows only a selection of BMPs. Other BMPs may also accomplish the goals of invasive removal and re-establishment of native species. Watershed planners should consult with HDOH when developing project plans to ensure BMP eligibility.

many BMPs; ensuring that native species are used (and in the necessary quantities for establishment) will help to restore native plant communities. Managing invasive animal species is typically limited to exclusion or removal.

Table 1. Selection of BMPs to Address Invasive Species

Management Practice	**Description**
Bioretention Cell (Rain Garden)	Depression consisting of native plant species and soil mixtures that receives stormwater flow and infiltrates to treat pollutants.
Channel Maintenance and Restoration	Practices used to control sediment and plant pollution into waterways during earthwork such as stream bank stabilization or habitat enhancement. Examples include floating booms and silt curtains extended across river or stream banks downstream of work.
Constructed Wetlands	Creation of an artificial wetland ecosystem to improve the quality of stormwater runoff or other water flows. A constructed wetland provides biological treatment in areas where wetland function can be created or enhanced. Constructed wetlands also can be used to treat runoff from agricultural land uses and stormwater runoff and other contaminated flows from urban areas and other land uses. The practice involves establishment of inlet and outlet control structures for an impoundment designed to accumulate settleable solids, decayed plant matter, and microbial biomass and support propagation of hydrophytic vegetation.
Critical Area Planting	Establishment of permanent vegetation in areas with heavy erosion problems. Particularly useful for areas that need stabilization before/after flood events.
Grassed Waterway	A shaped or graded channel that is established with suitable vegetation to convey surface water at a non-erosive velocity using a broad and shallow cross section to a stable outlet. Used to convey runoff from terraces, diversions, or similar; to prevent gully formation; and to protect or improve water quality.
Herbaceous Weed Treatment/Invasive Species Removal	The removal or control of herbaceous weeds, including invasive, noxious, and prohibited plants.
Sediment Basin	Captures and retains stormwater runoff until sediments settle out; water is released through engineered outlet.
Feral Ungulate Fencing	A structural conservation practice that prevents movement of ungulates across a given boundary. Within areas impacted by feral ungulate presence, fences prevent their movement into the forested lands. Ungulate fencing prevents direct contact of fecal matter with waterways, allows for restoration of vegetation, and reduces bacteria and nitrogen loadings and sediment input into waterways.
Feral Ungulate Removal	Hunting or trapping wild goats, pigs, and other non-native hoofed mammals to reduce erosion caused by trampling and vegetation

Management Practice	Description
	removal, as well as nutrient and bacterial impacts from defecation in and around water bodies.

Through this addendum, these BMPs are now eligible for funding under Section 319 to address water quality concerns caused by invasive species (if the BMPs were not already identified in the original plan). Implementation of these BMPs will lead to a reduction in pollutant loading in the watershed. The original watershed-based plan may include information on specific locations or land use types that may be most appropriate for invasive species BMPs. Additional information can be found in other resources, such as the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service's *Field Office Technical Guide* for Hawaii.[3]

Calculating Pollutant Reductions

Accounting for the total pollutant reductions is an important step in tracking water quality improvements. HDOH and watershed stakeholders develop watershed-based plans under the state's nonpoint source pollution (NPS) program; these plans include a projected level of pollutant reduction for the proposed project.

There are various models that can be used to calculate the pollutant reductions associated with BMP implementation. HDOH researched the advantages and disadvantages of each model, including the ease of use for watershed project managers and evaluating the model's appropriateness for use in Hawaii. After reviewing several models, HDOH selected the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model.

Description of the InVEST Model

InVEST is a suite of models focused on ecosystems and how they connect to downstream economics. This addendum is focused on the sediment delivery ratio model in the InVEST suite. The InVEST sediment delivery ratio model was chosen by HDOH because it is easy to use and its ability to estimate sediment loading both with current condition and with BMPs implemented. Additionally, the InVEST model can be modified to accommodate the unique geologic conditions in Hawaii.

The InVEST sediment delivery ratio model is focused on sediment loading and erosion. The model outputs a set of maps showing the sediment erosion, including the amount of sediment soil loss per pixel, and the amount of erosion that is prevented by the presence of vegetation per pixel. The effect of BMPs on sediment erosion can be measured by comparing model outputs ran under the current conditions against model outputs ran with BMPs implemented. To calculate the annual soil loss per pixel, the InVEST model uses the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997). Along with the factors that are in the RUSLE equation (rainfall erosivity, soil erodibility, slope length gradient, cover management, and support practice), this addendum recommends including an additional terrain factor to accommodate for the geology of Hawaii. The inclusion of the terrain factor prevents the model from overestimating the soil loss in places with geologically new basaltic bedrock which has minimal soil cover (Falinski, 2016).

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[3] https://efotg.sc.egov.usda.gov/#/state/HI/documents

The required data inputs for this model are integrated into the RUSLE equation. To determine the effects of BMPs on sediment load reduction and erosion, the model should be run with altered data inputs.

The required data inputs include GIS data, a table, and five additional values. These five inputs are described in detail in the Step-by-Step Procedure below. To measure the reduction in sediment load and erosion with BMP implementation, these inputs can be changed to integrate the increase in vegetation that would come along with BMP implementation. The Step-by-Step Procedure section of this addendum describes each of these required inputs in further detail along with recommended values and sources for GIS data inputs.

Step-by-Step Procedure

The step-by-step procedure begins with collecting and creating the proper data inputs for the current conditions in the watershed and running the InVEST model with those data inputs. After the first model run, the next step is to use multiple lines of evidence, including model outputs and other information, to determine the most appropriate areas in the watershed to implement BMPs. Next, the model should be run again with inputs that incorporate the impacts that BMPs would have on the land cover or support practices. The reduction in pollutant loading is the difference between the two model output runs. The steps to compile each data input and descriptions of each required data input are shown in Table 2. All GIS inputs must be the same coordinate reference system. The coordinate reference system must be projected and in linear units of meters.

Table 2. Required Data Inputs for the Invest Model

GIS Data Inputs		
Input Name and Description	**Data Type**	**Suggested Sources**
Digital Elevation Model: A digital elevation map (DEM) showing elevation in meters. The map should be clipped beyond the watershed boundary.	Raster	The 3D Elevation Program (3DEP) from USGS.[4] The best available resolution for the state is 1/3 arc-second.
		The Hawaii Statewide GIS Program's Digital Terrain Model.[5] Data is only available for portions of the state and as a JPEG or PNG, so it must be converted to a raster format. The resolution is 1 meter, and the elevation values are in meters.
Erosivity: A map of rainfall erosivity in units of MJ • mm/(h • ha • year). The map should illustrate both intensity and duration of rainfall.	Raster	For the island of Hawaii, NOAA's digitized version of the rainfall erosivity map from the Agriculture Handbook No. 703.[6] The units are US customary units, so the units must be converted by multiplying each value by 17.02 (Renard, et al., 1997).
		For the island of Oahu, NOAA's digitized version of the rainfall erosivity map from the Agriculture Handbook No. 703.[7] The units are US customary units, so the units must be converted by multiplying each value by 17.02 (Renard, et al., 1997).
		The rainfall erosivity map on page 57 of the Agriculture Handbook No. 703. This map must be digitized into raster data by a GIS specialist and units must be converted to SI by multiplying each value by 17.02 (Renard, et al., 1997).
		A rainfall erosivity raster can be made using precipitation from the Hawaii Climate Data Portal.[8] Rainfall erosivity can be calculated using the Roose equation (Renard and Freimund, 1994): R = 0.5 x P x 17.02, where R is the rainfall erosivity value in the proper SI units and P is the annual rainfall in mm/year.
Soil Erodibility: A map showing the soil erodibility in the watershed. Soil erodibility, also called K factor, is the likelihood of soil particles to erode and be transported downstream by	Raster	Soil data, including K factors, is available from the Soil Survey Geographic Database (SSURGO).[9] This database provides raster data of soil type in an area of interest, and a table showing the K factor of each soil type. Raster data of K factors in a projected coordinate system will

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[4] https://apps.nationalmap.gov/downloader/

[5] https://geoportal.hawaii.gov/datasets/HiStateGIS::hawaii-dtm-elevation/about

[6] https://www.fisheries.noaa.gov/inport/item/48225

[7] https://www.fisheries.noaa.gov/inport/item/48230

[8] https://www.hawaii.edu/climate-data-portal/data-portal/

[9] https://www.nrcs.usda.gov/resources/data-and-reports/soil-survey-geographic-database-ssurgo

precipitation or runoff. The soil erodibility raster must be in units of t · h · ha / (ha · MJ · mm).		have to be generated by combining the soil raster data and the K factor table.
Land Use/Land Cover: A map showing the land use and land cover within the watershed. The C-CAP raster described below must also be combined with geology data. Each pixel should be categorized by its land use/land cover and geologic origin from the geology dataset. Every combination of land use/land cover and geologic origin should be assigned a unique LULC code.	Raster	NOAA has C-CAP high resolution land cover raster data available for the entire state of Hawaii from 2021.[10] NOAA's land cover data has a resolution of 1-meter and includes up to 25 classifications including forests and urban development.
		Geology data for the state of Hawaii is available for download from USGS.[11] This data is available as shapefiles, so it must be converted to raster data.
Watersheds: A map of the boundary of the watershed.	Vector (polygon/ multipolygon)	The USGS Watershed Boundary Dataset has vector watershed delineation data available at different hydrologic unit levels for the entire state of Hawaii.[12]
		The Hawaii Statewide GIS Program has vector watershed delineation data available that was created by the Division of Aquatic Resources (DAR).[13]
		The InVEST suite includes the Delineatelt tool, used for generating watersheds based on user inputs. This tool outputs a GeoPackage containing a vector with the model's estimated watershed delineations. More information on this tool can be found in the Delineatelt section of the InVEST suite.[14]
		Watershed delineations can be generated using a USGS StreamStats's tool.[15] Delineations can be downloaded as vectors.
Other Required Data Inputs		
Input Name and Description	**Data type**	**Suggested Input Value**
Threshold Flow Accumulation: The minimum number of pixels that flow into another pixel for it to be classified as a stream.	Number of pixels	This value should be determined by the user via trial and error. Users should test different values until the streams on the output maps resemble the streams in the watershed.

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[10] https://coast.noaa.gov/digitalcoast/data/

[11] https://pubs.usgs.gov/of/2007/1089/

[12] https://www.usgs.gov/national-hydrography/watershed-boundary-dataset

[13] https://geoportal.hawaii.gov/datasets/HiStateGIS::watersheds-dar-version/about

[14] https://storage.googleapis.com/releases.naturalcapitalproject.org/invest-userguide/latest/en/delineateit.html

[15] https://www.usgs.gov/streamstats

Borselli k Parameter: A calibration parameter in the sediment delivery ratio equation.	Number	This value is based on watershed location. Table 3 shows the Borselli k Parameter by location.
Maximum SDR Value: The maximum sediment delivery ratio a pixel is allowed to have.	Number between 0 and 1	For all watersheds in the state of Hawaii, the value should be 0.5 (Falinski, 2016).
Borselli IC_0 Parameter: A calibration parameter in the sediment delivery ratio equation.	Number	For all watersheds in the state of Hawaii, the value should be 0.1 (Falinski, 2016).
Maximum L Value: The maximum allowed slope value in the slope length-gradient factor.	Number	For all watershed in the state of Hawaii, the value should be 122 (Falinski, 2016).
Biophysical Table: A table mapping each LULC code to its cover-management factor (C) and support practice factor (P). One column should be named "lucode" and contain the LULC code from the land cover and land use raster. The other two columns should be named "usle_c" and "usle_p" and contain the associated C factor and P factor, respectively. The C factor indicates how much erosion is likely to occur at this land use/land cover type. The smaller the C factor value, the less erosion is expected to come from that type. To account for the terrain factor in the model run, the C factor in the biophysical table should be modified. The C factor for each LULC code should be the original C factor from Table 4 multiped by the terrain factor from Table 5 that is associated with the geologic origin under that LULC code. The P factor indicates whether erosion reduction practices are implemented in that area. A value of 1 means there are no erosion reduction practices implemented in that land cover/land use type and a smaller value indicates best management practices are implemented in that land cover/land use type.	.CSV file	Table 4 shows the C factors for land use/land covers in Hawaii, and Table 5 shows the terrain factor by geologic origin.
Workspace: The folder where outputs will be written.	Folder name	--

Table 3. Borselli k Parameter by Watershed Location (Falinski, 2016)

Watershed Location	Borselli k Parameter
Windward part of the island of Hawaii	4
Leeward part of the island of Hawaii	2.5
Oahu	2.5
Maui	2
Lanai	2
Molokai	1.25
Kahoolawe	2.4
Kauai	1.6
Niihau	1.5

Table 4. C Factor Values for Land Use/Land Cover (Falinski, 2016)

Land Use/Land Cover	**C Factor**	**Land Use/Land Cover**	**C Factor**
Evergreen	0.014[16]	Developed, Medium Intensity	0.01
Scrub Shrub	0.014[17]	Impervious Surface	0.001
Bare Land	0.7	Palustrine Scrub Shrub Wetland	0.003
Pasture/Hay	0.05	Palustrine Emergent Wetland	0.003
Grassland	0.05	Unconsolidated Shore	0.003
Open Water	0	Estuarine Forested Wetland	0.003
Cultivated Land	0.24[18]	Estuarine Scrub Shrub Wetland	0.003
Developed, Low Intensity	0.03	Estuarine Emergent Wetland	0.003
Palustrine Forested Wetland	0.003	Background	0
Open Space Developed	0.05	Palustrine Aquatic Bed	0

Table 5. Terrain Factor by Geologic Origin (Falinski, 2016)

Hawaii		**Oahu, Kauai and Niihau**	
Geologic origin	**Terrain factor**	**Geologic origin**	**Terrain factor**
Hamakua Volcanics	1	Honolulu Volcanics	1
Hawi Volcanics	1	Kolekole Volcanics	1
Hilina Basalt	0.001	Koolau Basalt	1
Hualalai Volcanics	0.001	Waianae Volcanics	1
Kahuku Basalt	0.001	Kiekie Volcanics	1
Kau Basalt	0.001	Koloa Volcanics	1
Laupahoehoe Volcanics	0.1	Paniau Basalt	0.1
Ninole Basalt	1	Waimea Canyon	0.1
Pololu Volcanics	1	--	--
Puna Basalt	0.001	--	--

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[16] Evergreen forest: 0.035 for Hamakua and Kohala volcanoes

[17] Scrub/shrub: 0.05 for leeward volcanic units

[18] Cultivated land: 0.4 for pineapple (Lanai) or 0.51 for sugarcane crop (central Maui)

Maui, Molokai, Lanai and Kahoolawe		**All Islands**	
Geologic Origin	**Terrain factor**	**Geologic origin**	**Terrain factor**
East Molokai Volcanics	1	Open water	1
Hana Volcanics	0.001	Fill	1
Honolua Volcanics	1	Alluvium	1
Honomanu Basalt	1	Landslide Deposits	1
Kalaupapa Volcanics	1	Slope Deposits	0.001
Kanapou Volcanics	1	Tephra Deposits	0.1
Kaupo Mud Flow	1	Beach Deposits	0.1
Kula Volcanics	0.01	Lagoon Deposits	1
Lahaina Volcanics	1	Older Dune Deposits	1
Lanai Basalt	1	Younger Dune Deposits	0.1
Wailuku Volcanics	1	Talus and Colluvium	0.1
West Molokai Volcanics	1	Marine Conglomerate and Breccia	0.1
--	--	Caldera Wall Rocks	0.001

The most relevant output is the "sed_export.tif', showing the sediment exported from every pixel. Because of the geology of Hawaii, data on the pixel level from this raster may be inaccurate. The model tends to predict higher sediment export from areas with steeper slopes. In Hawaii, high slopes occur in high elevation areas where the sediment supply may be naturally limited by the unique geology of Hawaii. Therefore, the model overestimates the amount of sediment export in the mountains because it assumes unlimited sediment supply in steep areas with thin or little soil. For this reason, the sediment export raster data should not be used as the sole or main method for determining where BMPs should be implemented within the watershed.

The sediment export raster can be combined with land use/land cover data to determine which land use classes are disproportionately contributing to sediment loading. The amount of sediment mass exported per acre for each land use can be calculated by adding up the value of every pixel in the sediment export raster in each land use and dividing that sum by the number of acres that the land use covers.

It is crucial that multiple lines of evidence are considered when determining where BMPs should be implemented. The normalized difference vegetation index (NDVI)[19] is a satellite-based measurement that could be useful in identifying areas with minimal vegetation which may be susceptible to increased erosion. The NDVI quantifies vegetative health and density. NDVI values closer to positive 1 indicate the presence of abundant and healthy vegetation, and a value closer to 0 indicates there is less vegetation (NASA, 2025). Looking at NDVI data in a raster format would allow a user to visualize areas within the watershed that have little vegetation or unhealthy vegetation, indicating that the area could benefit from BMP implementation. If the

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[19] One potential source of NDVI data is NOAA's Suomi National Polar-orbiting Partnership (Suomi NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Vegetation Indices (VNP13A2) Version 2 data product which can be queried using the 'modisfast' R package.

resolution of the NDVI data is a lower resolution, it may be difficult to pinpoint areas where BMP implementation would be the most valuable. Therefore, further evidence should be used when selecting areas for BMP implementation. A high resolution and recent satellite image can supplement older land use/land cover data and lower resolution NDVI raster data. A satellite image can be used to more accurately identify areas with minimal vegetative cover which could benefit most from BMP implementation. Further useful evidence can be collected on-site in the watershed. If possible, a person can walk along streams in the watershed and identify locations in the watershed where BMP implementation would be the most advantageous, such as locations with invasive plant species, minimal vegetation and/or the presence of feral ungulates. Each of the options listed above is important evidence that should be considered when the user is deciding on locations for BMP implementation.

After determining where BMPs will be implemented, the next step is to re-run the model with inputs that account for the BMPs that would be implemented to determine how they would affect sediment loading. The model inputs for the revised run should remain almost entirely the same. A different directory should be entered into the Workspace field or the results from the last model run will be overwritten. Additionally, either the support practice factors in the biophysical table or the land use/cover raster should be edited:

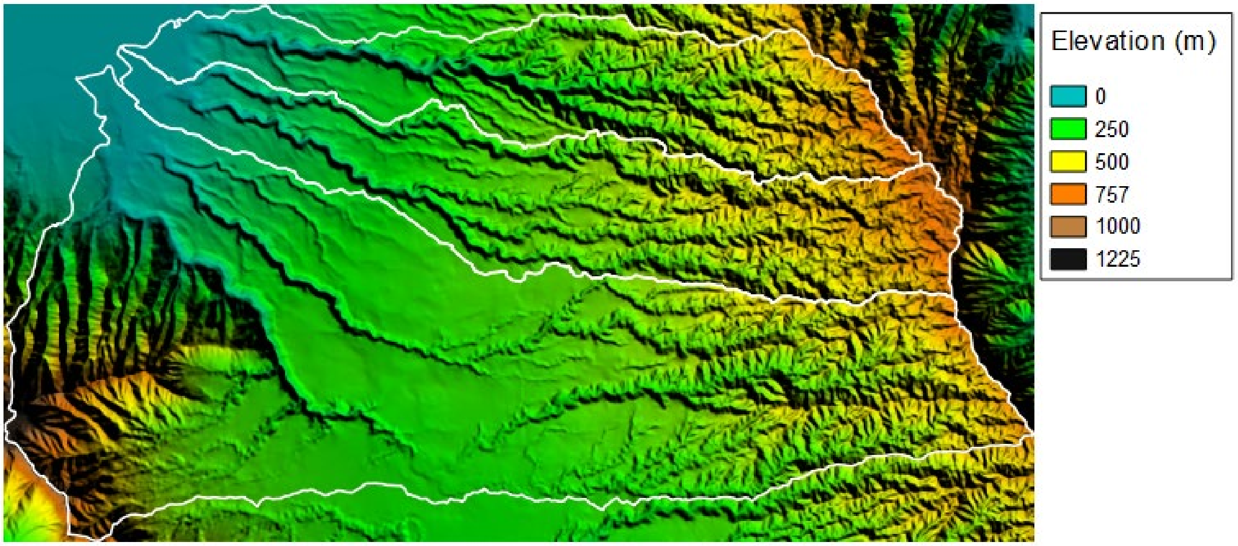
- The P factors in the biophysical table should be decreased for each land use/land cover type where an erosion reduction practice will be implemented.
- Alternatively, the land cover/land use raster should be edited to show how the land use/land cover would change with erosion reduction practices implemented. For example, bare land could be changed to a type of forest cover if a best management practice would be to plant native species on non-vegetated land.

To determine the effect that the implementation of best management practices would have on sediment exports, the outputs from both model runs can be compared. The sum across every pixel in "sed_export.tif" outputs illustrate how much sediment load reduction would occur with BMP implementation on the watershed level.

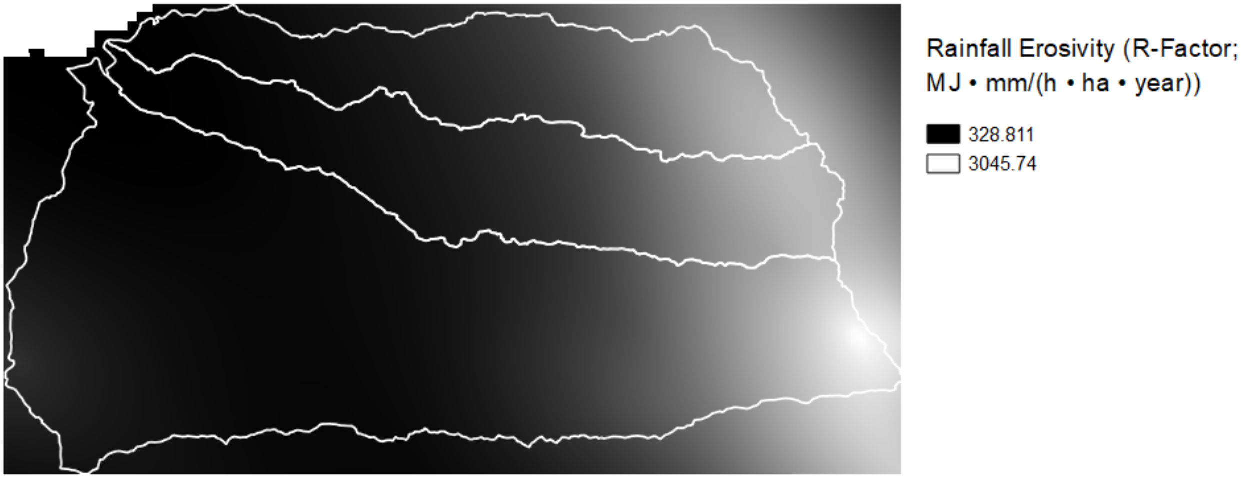
Example Use of the Procedure

To illustrate the Step-by-Step Procedure, this section looks at an example watershed: Kaiaka Bay. The Kaiaka Bay watershed is on the coast of the island of Oahu. The Kaiaka Bay and several streams that drain into the bay are listed as impaired. Both invasive plant species and feral ungulates are thought to cause high levels of erosion in this watershed, making the Kaiaka Bay watershed a good example watershed for the procedure (AECOM et al., 2018). The GIS data inputs for the InVEST model must all be in the same projected coordinate reference system, so every GIS data input is in the NAD83 coordinate reference system. The data inputs used for running the model with current conditions are below:

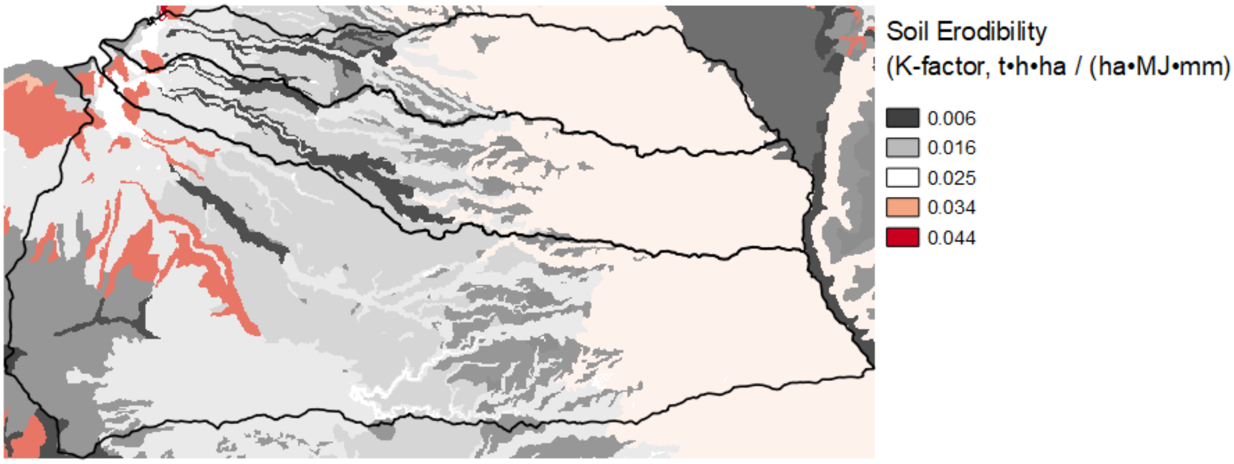
- Elevation Map: A DEM raster showing elevation in meters in the Kaiaka Bay and the surrounding area. This raster is a valid input for the InVEST model because the elevation is in meters and it extends beyond the Kaiaka Bay watershed boundary.



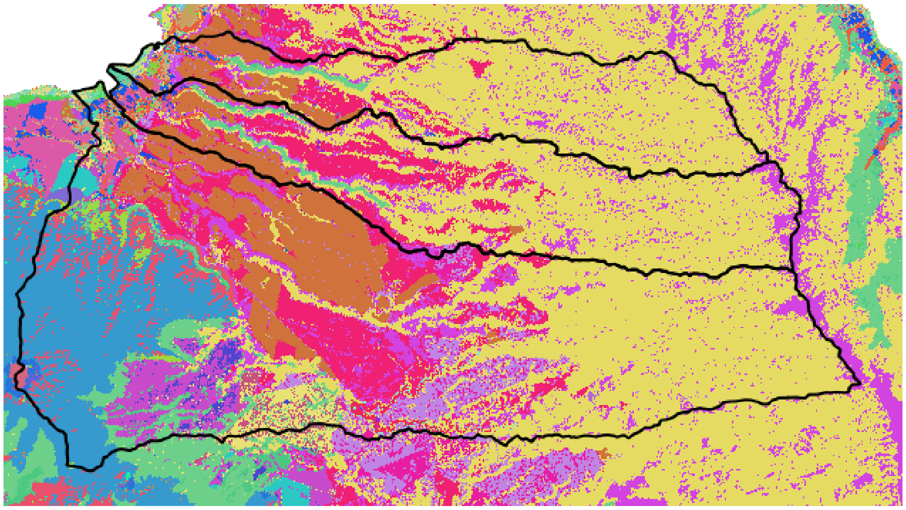
- Rainfall Erosivity: A rainfall erosivity map in raster format showing the rainfall erosivity throughout the Kaiaka Bay watershed in MJ • mm/(h • ha • year), the units required by the model.



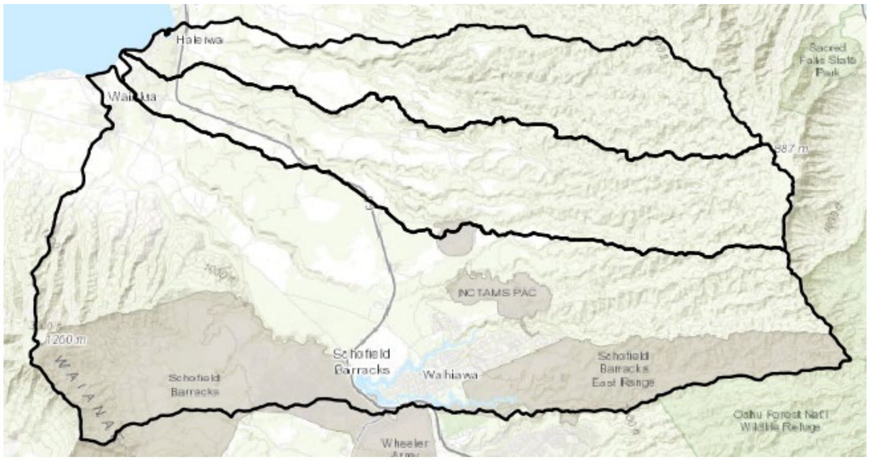
- Soil Erodibility: A map showing soil erodibility, or K factors, within the Kaiaka Bay watershed in raster format. The values in the raster format are in the proper units for the model, t • h • ha / (ha • MJ • mm).



- Land Use & Land Cover and Geologic Formation: A raster categorizing the land in Kaiaka Bay watershed by their land use/land cover and their geologic formation. This raster has over 1000 land cover/geologic formation categories, but not all categories have pixels that belong to them. Each land cover/geologic formation category has a unique LULC code so that this raster can be connected to the biophysical table.



- Watershed boundary: A vector outlining the Kaiaka Bay watershed.



- Threshold Flow Accumulation: 200. Value was derived through trial and error, and was identified when the delineated stream network approximately matched the "real" stream network for the watershed.

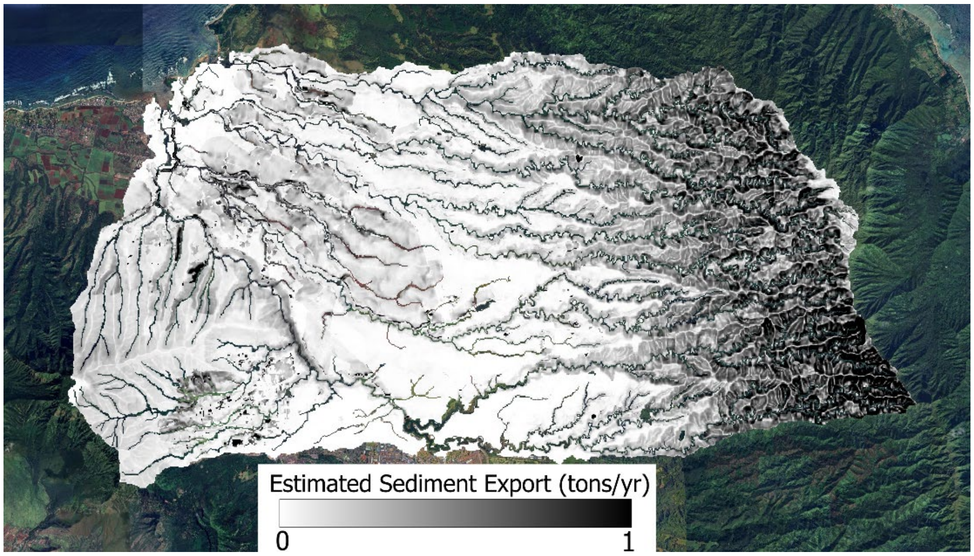
- Borselli k Parameter: The Borselli k parameter for this model run is 2.5, the value for all watersheds on Oahu.

- Maximum SDR Value: The maximum SDR value for this model run is 0.5, the value for all watersheds on the state of Hawaii.

- Maximum L Value: The maximum L value for this model run is 122, the value for all watersheds on the state of Hawaii.

- Biophysical Table: The biophysical table for this model run contains a column with each LULC code from the land use and land cover raster. Each LULC code is mapped to a modified C factor that is the original C factor from Table 4 multiplied by the terrain factor from Table 5 or the geologic origin associated with the LULC code. For example, a small piece of land in the Kaiaka Bay watershed is scrub shrub land (C factor = 0.014) with beach deposits as its geologic formation (terrain factor = 0.1), so the modified C factor in the biophysical table is 0.0014. The P factor for every LULC code is 1 because no support practices have been implemented in this watershed.

Once the inputs have been gathered, the baseline scenario is run. The model outputs suggest that a disproportionate amount of sediment export is occurring in the mountainous area of the Kaiaka Bay watershed. The sediment export raster is shown below:



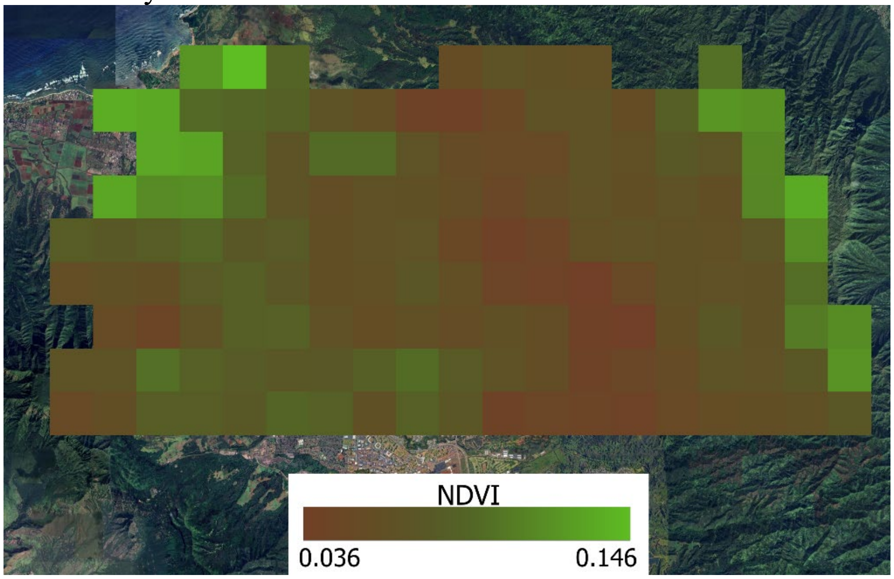
This raster indicates that the model expects the highest amount of sediment export to occur at the higher elevations of the watershed, but as discussed in the Step-by-Step Procedure section, the InVEST model tends to overestimate sediment export in high elevation areas. For this reason, multiple lines of evidence are considered when deciding on the locations for BMP implementation in this example. To determine the land class/land uses that contribute the most to sediment export relative to their area in the watershed, the pounds of sediment exported per acre is important evidence to evaluate as well. This value is calculated by adding the sediment export for every pixel in each land use/land cover and then dividing this sum by the acres each land use covers in the watershed. For example, bare land covers 405 acres of land in the Kaiaka Bay watershed and the model estimates that 1790.5 pounds of sediment are exported from bare land each year, so the pounds of sediment load per acre per year for bare land is 1790.5 divided by 405 which is 4.42. The sediment load per acre for each land use is shown in Table 6.

Table 6. Pounds of Sediment Load Per Acre Per Year by Land Use

Class	Edge of Stream Sediment Load (lbs/acre/year)
Developed, High Intensity	0.00
Developed, Med Intensity	0.00
Developed, Low Intensity	0.00
Developed, Open Space	0.11
Cultivated Crops	1.08
Pasture/Hay	0.26
Grassland/Herbaceous	0.44
Evergreen Forest	1.37
Scrub/Shrub	0.90
Palustrine Emergent Wetland	0.01
Palustrine Forested Wetland	0.01
Palustrine Scrub/Shrub Wetland	0.01
Estuarine Forested Wetland	0.03

Class	Edge of Stream Sediment Load (lbs/acre/year)
Estuarine Scrub/Shrub Wetland	0.23
Unconsolidated Shore	0.00
Bare Land	4.42
Open Water	0

This table indicates that bare land areas contribute the most sediment per acre in the Kaiaka Bay watershed, so bare land within the watershed may be a beneficial target for BMP implementation. Planting native plant species could minimize the sediment load coming from areas that are currently bare land by transforming it into vegetative cover (or evergreen forest in terms of land cover classes). Currently, bare land covers 405 acres of the watershed and the sediment export from this land is 1790.5 pounds. To calculate the amount of sediment load from this land after BMP implementation, assuming all the bare land becomes evergreen forest, the acres of bare land should be multiplied by the sediment load per acre for evergreen forest. This returns a value of 554.85 pounds of sediment load per year from this land, a 1235.65 pound decrease. These calculations should be considered when selecting locations for BMP implementation, but additional evidence should be evaluated as well. As discussed in the Step-by-Step Procedure section, NDVI data can be useful evidence as well. The NDVI data in raster format for the Kaiaka Bay is below:



The pixels with a lower NDVI index, which are shown in darker brown, are less vegetated areas. This image indicates that the middle section of the Kaiaka Bay watershed is less vegetated, so BMP implementation could be especially valuable in this area. However, the resolution of this raster data is low, so it is difficult to use it to precisely choose locations for BMP implementation. Therefore, other evidence such as high-resolution satellite images and drone footage can be used to pinpoint areas with minimal or invasive vegetation. As an additional line of evidence, people familiar with the Kaiaka Bay watershed can be interviewed to collect information on areas with minimal vegetation, invasive plants and/or feral ungulates. Furthermore, a person can walk along streams in the Kaiaka Bay watershed and document the most eroded areas. The information gathered from the InVEST model run, the NDVI index raster, satellite images, drone footage, interviews and documentation from someone on site should all be carefully considered when determining where BMPs should be implemented.

Useful Resources and Materials

To supplement the information included in this addendum, more information on the InVEST model and using this model in the state of Hawaii is linked below:

- More information on the InVEST sediment ratio delivery model including background information, required data inputs, and guidance on interpreting outputs is here: SDR: Sediment Delivery Ratio — InVEST® documentation
- More information on the InVEST DelineateIt tool discussed in the Step-by-Step Procedure to create watershed boundaries: DelineateIt — InVEST® documentation
- Further details on the Kaiaka Bay watershed: Kaiaka Bay Watersheds Characterization
- For more information on running the InVEST model for watersheds in Hawaii, including the rationale for many of the non-GIS inputs see Predicting Sediment Export into Tropical Coastal Ecosystems to Support Ridge to Reef Management [dissertation], available for download here: (PDF) PREDICTING SEDIMENT EXPORT INTO TROPICAL COASTAL ECOSYSTEMS TO SUPPORT RIDGE TO REEF MANAGEMENT

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United States Geological Survey (USGS). 2025. 1/3rd arc-second Digital Elevation Models (DEMs) - USGS National Map 3DEP Downloadable Data Collection. https://data.usgs.gov/datacatalog/data/USGS:3a81321b-c153-416f-98b7-cc8e5f0e17c3