# Forest Management Plan
# Waimānalo Forest Reserve, Oʻahu

**Forest Solutions Inc., 2013**

**10 July 2014**



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## Project Information Sheet

| | |
|---|---|
| Owner: | State of Hawaiʻi Division of Forestry and Wildlife |
| Representative: | Ryan K. I. Peralta<br>Forest Management Supervisor I<br>State of Hawaiʻi<br>Division of Forestry and Wildlife<br>2135 Makiki Hts Dr.<br>Honolulu, HI 96822<br>Ryan.K.Peralta@hawaii.gov<br>Office: +1 (808) 973-9784 |
| Tax Map Key numbers: | 4-1-8:13, 4-1-10:93, 4-1-10:74, 4-1-10:94 |
| Zoning designation: | Conservation District, Resource Subzone |
| Area: | 483.6 acres (195.7 hectares) |
| Proposed land use: | Watershed protection (174.3 acres)<br>Timber (76.3 acres)<br>Agroforestry (212.2 acres)<br>Public access (20.9 acres) |
| Geography: | Slope range: 0% to 83%<br>Elevation: (200) ft to (900) ft |
| Hydrology: | Seasonal streams: 1 |
| Public record: | Plan synopsis available from March 18th 2013<br>Appendix A |
| Plan consultant: | Forest Solutions, Inc.<br>Thomas Baribault, Ph.D.<br>67-1435 Mamalahoa Hwy<br>Kamuela, HI 96743<br>Tom@hawaiiforest.com<br>Office: +1 (808) 776-9900 x 238 |

## Signatures and Certifications

**Professional Resource Consultant Certification**:

I have prepared (or revised) this Forest Stewardship Plan. Resource professionals, community representatives, and potential contractors have been consulted and/or provided input as appropriate during the preparation of this plan.

Prepared by: Forest Solutions, Inc.

Professional Resource Consultant's Signature/Date:

_____________________________________________|____________

Professional Resource Consultant's Name: Thomas Baribault, Ph.D.

**Client Certification**:

I have reviewed this Forest Stewardship Plan and hereby certify that I concur with the recommendations contained within. I agree that resource management activities implemented on the lands described shall be done so in a manner consistent with the practices recommended herein.

Prepared for: State of Hawaiʻi, Department of Land and Natural Resources, Division of Forestry and Wildlife

Client's Signature/Date:

_____________________________________________|____________

Client's Representative: Ryan K. I. Peralta.

PLEASE NOTE that the financial models included in this proposal are forest management tools to assist in forecasting estimated project performance. The financial models and their included projections are reasonable assumptions of project performance based upon prior experience but they are not, and should not be considered as, a guarantee of a particular project's outcome by Forest Solutions. Forest Solutions is not a financial advisor and the financial models and their projections we provide should not be used to make financial or investment decisions. Such decisions should only be made with the advice of, and based upon the recommendations of, your financial advisors.

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## Executive Summary

The State of Hawai'i Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW), will pursue improved forest management in the Waimānalo Forest Reserve (WFR) located at the Northwest end of Waimānalo Valley, windward O'ahu. The WFR, which occupies nearly 500 acres, is forested by invasive species, primarily *Acacia confusa*, *Falcataria moluccana*, and *Schefflera actinophylla*; forest cover is complete in the majority of the reserve. Hawai'i Forest Reserves are managed for watershed protection, public outdoor recreation, biodiversity of native Hawaiian species, and economic outputs from forest products. The WFR currently receives minimal management intervention, but nonetheless succeeds in watershed protection and provision of public recreation opportunities. **The principal objective of the present forest management plan is to define management prescriptions that improve native Hawaiian species biodiversity and forest productivity in the WFR, while maintaining watershed protection and ensuring public recreation access.**

This forest management plan proposes four forest management classes (FMC) defined by slope, vegetation cover, and accessibility. The FMC include watershed conservation and restoration areas, high-value hardwood timber planting areas, agroforestry sections, and public trail access routes.

i. Watershed conservation and restoration will consist of native Hawaiian tree and understory species planted on steeper slopes to stabilize soils and improve biodiversity.
ii. High-value hardwood timber plantings will occur on intermediate slopes in areas with somewhat limited access, and will include species such as koa, milo, mahogany, and teak.
iii. Agroforestry management practices will be implemented in areas with shallower slopes and good accessibility, and may include tree crops such as cacao, jackfruit, ulu, avocado, coffee, niu, lychee, or numerous other species to be selected by interested stakeholders.
iv. Public recreation access via Nā Ala Hele trails (Ditch Trail, Demonstration Trail) will remain a priority for DLNR DOFAW, particularly for unrestricted equestrian, cycling, and hiking access.

Forest management activities are planned to occur in two phases, with several optional scales at which projects can be implemented. During the first phase, which would last up to four years, various species, silvicultural, nutrient management, funding, and administrative trials will be installed and monitored. Within one or two years, information from these tests would allow the second phase to begin, which will involve applying trial results to larger, potentially commercial scales. Depending on the level of stakeholder interest and the availability of funding, this forest management plan could be implemented at four possible levels.

1. With limited funding up to $150,000, forest management could be improved across 12 acres of the WFR, including 8 acres of watershed restoration, 3 acres of agroforestry, and 1 acres of timber.
2. Greater funding availability at the $600,000 level would allow improved forest management on up to 81 acres, with 65 acres of timber, 11 acres of agroforestry, and 8 acres of watershed restoration.
3. More substantial funding on the order of $1.3 million would implement active forest management on as many as 146 acres: 110 acres of timber, 24 acres of agroforestry, and 12 acres of watershed restoration.
4. At the highest funding level ($1.9 million), nearly half of the WFR could be improved, with 163 acres of timber, up to 58 acres of agroforestry, and 21 acres of watershed restoration.

**The fundamental vision driving this management plan is forest improvement, acknowledging that current forest cover effectively conserves the watershed and provides public access, but that competent management will simultaneously improve native biodiversity and economic productivity in the Waimānalo Forest Reserve.**

# 1. Background

## 1.1. Project vision

As one of the few Oʻahu Forest Reserves on the windward side of the Koʻolau Mountain Range, the Waimānalo Forest Reserve (WFR) is an important area for watershed conservation and forest recreation. The State of Hawaiʻi Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW), supports four broad management objectives in the Forest Reserve System[1], including watershed protection, maintenance of biological integrity of native ecosystems, provision for public recreational opportunities, and strengthening local economies via forest products extraction. In the WFR, two of these objectives are adequately served: watershed protection and public recreational opportunity. In terms of watershed protection, the WFR is almost completely forested. This vegetation cover stabilizes the steeply sloping land at the Northwest end of the Waimānalo Valley, retaining soil, helping to mitigate flood damage, and improving downstream water quality. From a recreational perspective, two Nā Ala Hele trails, the Ditch Trail and the Demonstration trail, provide public cycling, hiking, and equestrian access to the 483 acres of the WFR. The Ditch Trail is particularly important to equestrian users, for whom it is the only publicly accessible trail on the entire island.

Whereas watershed protection and public recreation objectives are met by the current approach to forest management, other objectives have not been achieved. The WFR contains very few native Hawaiian species, with the vast majority of the area occupied by invasive tree species. Unfortunately, none of these species are economically useful, so there is little capacity for strengthening local economies by forest products extraction. The current forest management plan proposes several strategies to realign the condition of the WFR with broader DOFAW management goals.

Maintenance of adequate forest cover is the principal guideline followed by every management regime proposed in this plan. An intact forest is the foundation for each of the four State Forest Reserve management objectives; consequently, all forest improvement projects must work within the confines of maintaining forest cover from establishment through maturity. This plan proposes three forest management classes (FMC) that are consistent with the guideline: planting native tree and shrub species for watershed protection, planting high-value timber species, and establishing agroforestry systems of varying complexity for fruit and nut production. Detailed prescriptions, financial models, and project schedules are presented for each FMC, with examples sufficient for other entities to complete implementation. The plan would be implemented in two phases, the first involving site-specific research for species selection, soil testing, and marketing, and the second involving and expansion of promising projects from the first phase. Depending on stakeholder interest, community involvement, and funding, this forest management plan could be followed to improve as few as 10 acres or as many as 214 acres, at costs ranging from $130,000 through nearly $2 million.

Every forest management prescription proposed in this plan has been devised with the express purpose of improving alignment between DOFAW forest management goals and conditions on the ground. This vision for the Waimānalo Forest Reserve will continue to protect the watershed and rare public recreational opportunities while at the same time improving native ecosystem quality and economic prospects.

[1] http://hawaii.gov/dlnr/dofaw/forestry/FRS/mgnt-goals

## 1.2. Site description

### 1.2.1. Geography

The WFR is situated at the Northwest end of the Waimānalo Valley on the windward side of the Ko‘olau Mountain range, near Kailua town and Bellows Air Force Station (**Map 1**). The property spans four parcels, including Tax Map Keys (TMK) 4-1-8:13, 4-1-10:93, 4-1-10:74, and 4-1-10:94. The lowest areas at the Eastern edge of the WFR are less than 40 feet (12 m) above sea level, but the land rapidly ascends (**Fig. 1.2.1**) to more than 1080 feet (330 m) on its Northern ridge (**Map 1**). Altogether, the parcels cover 483.6 acres, of which of which approximately 150 acres contain slopes that exceed 40% (**Map 2**).

### 1.2.2. Biological summary

Whereas a suite of native Hawaiian plant and animal species once thrived in Waimānalo Valley, the area currently consists of a limited number of dominant non-native invasive tree and herbaceous plants. Animal life in the WFR likely consists of invasive birds, rodents, and similar small mammals; a biological survey was, however, beyond the scope of this forest management plan (FMP). Using a combination of field reconnaissance, State of Hawai‘i geographic information systems (GIS) data, and literature reports of the biota in similar areas, it is highly unlikely that any threatened or endangered (TE) species are present in the WFR. The extent of critical habitat in the Ko‘olau Mountains is constrained to higher elevation areas on the Southwest edge of the Waimānalo Valley (§VII).

#### *1.2.2.1. Dominant invasive trees and shrubs*

The flora in the WFR is typical for windward O‘ahu, with a cosmopolitan overstory of invasive trees, including chiefly albizia, octopus tree, and Formosan koa (**Fig. 1.2.2**), with the remainder of the overstory or midstory comprising a variety of fast-growing, relatively drought tolerant species (**Table 1.2.1**). According to the University of Hawai‘i (Mānoa) Weed Risk Assessment (WRA), all of these species present a serious invasive threat, scoring at least 5 on the risk scale, and as much as 24.

**Table 1.2.1 Common overstory and midstory invasive species in the WFR.**

| Genus | Species | Common | Weed Assessment Rank† | Weed Assessment Designation‡ | Growth habit |
|---|---|---|---|---|---|
| *Falcataria* | *moluccana* | albizia | 8 | H(HPWRA) | Overstory |
| *Schefflera* | *actinophylla* | octopus tree | 13 | H(Hawaii) | Overstory |
| *Acacia* | *confusa* | Formosan koa | 10 | H(Hawaii) | Overstory |
| *Ficus* | *microcarpa* | Chin. banyan | 10 | H(HPWRA) | Overstory |
| *Schinus* | *terebinthifolius* | Christmas berry | 19 | H(Hawaii) | Overstory |
| *Grevillea* | *robusta* | silk oak | 5 | EVALUATE | Overstory |
| *Cytharexylum* | *spinosum* | fiddlewood | 7 | H(HPWRA) | Midstory |
| *Syzygium* | *cumini* | Java plum | 7 | H(HPWRA) | Midstory |
| *Psidium* | *cattleianum* | Strawberry guava | 18 | H(Hawaii) | Midstory |
| *Psidium* | *guajava* | Common guava | 21 | H(Hawaii) | Midstory |
| *Pimenta* | *dioica* | allspice | 7 | H(HPWRA) | Midstory |
| *Leucaena* | *leucocephala* | haole koa | 15 | H(HPWRA) | Midstory |

†Weed risk rank: 0 = no threat | < 5 = medium threat | > 5 = high threat

‡H(HPWRA): likely invasive | H(Hawaii): documented invasive | EVALUATE: under review

**Figure 1.2.1. Some of the most common aggressive overstory invasive species include *F. moluccana* (left) and *A. confusa* (right).**

Common understory or herbaceous species (Table 1.2.2) present similar invasion threats as assessed by capability to rapidly reproduce and infiltrate new territory. In the context of a forestry and agroforestry FMP, these understory species constitute the most likely root space and soil nutrient competition for desirable fruit and timber tree species. Of particular concern are fast-growing, aggressive shrubs such as *Clidemia hirta* that have the ability to out compete height growth rates of most tree species during the first two years after establishment.

**Table 1.2.2. Common understory invasive plants in the WFR.**

| Genus | Species | Common | Weed Assessment Rank† | Weed Assessment Designation‡ | Growth habit |
|---|---|---|---|---|---|
| *Oplismenus* | *hirtellus* | basket grass | NA | NA | Understory |
| *Sphagneticola* | *trilobata* | wedelia | 13 | H(HPWRA) | Understory |
| *Lantana* | *camara* | lantana | 21 | H(Hawaii) | Understory |
| *Rubus* | *argutus* | blackberry | 22 | H(Hawaii) | Understory |
| *Passiflora* | *spp* | passionflower | <24 | H(HPWRA) | Understory |
| *Clidemia* | *hirta* | Clidemia | NA | NA | Understory |
| *Coccinia* | *grandis* | ivy gourd | 21 | H(Hawaii) | Understory |
| *Macaranga* | *mappa* | bingabing | 11 | H(Hawaii) | Understory |
| *Ardisia* | *elliptica* | ardisia | 11 | H(Hawaii) | Understory |
| *Xanthium* | *strumarium* | cocklebur | NA | NA | Understory |

†Weed risk rank: 0 = no threat | < 5 = medium threat | > 5 = high threat

‡H(HPWRA): likely invasive | H(Hawaii): documented invasive | EVALUATE: under review

### *1.2.2.2. Remnant native trees and shrubs*

On reconnaissance visits during the preparation of this FMP, sightings of native Hawaiian species were limited to a single midstory species and likewise one understory species. The valuable hardwood tree known as milo (*Thespesia populnea*) was encountered at several locations along the Waimānalo Ditch Trail, which is a lower elevation area; one individual was encountered along the Demonstration Trail at intermediate elevation, suggesting that most naturally occurring milo would probably occur at less than 500 feet above sea level. The drought tolerant shrub ulei (*Osteomeles anthyllidifolia*) grew in at least three places along the Ditch Trail (Figure 1.2.2) and in one location adjacent to the Demonstration trail at a higher elevation.

**Figure 1.2.2. The two native Hawaiian plant species sighted in the WFR are the drought tolerant shrub *O. anthyllidifolia* (above) and *T. populnea*, a valuable tree species.**

### 1.2.3. Geochemistry

#### *1.2.3.1. Soils*

The most common soil types (Map 3) represented across the WFR include seven broad soil classes (Table 1.2.3), most of which are well drained (Map 4), and all of which can be described as fine-textured substrates that are primarily acidic (Map 5). From the perspective of their susceptibility to erosion, these soil types behave somewhat differently depending on the slope of the terrain on which they occur, but generally show similar physical and nutrient profiles (Appendix A). Broadly, WFR soils are very low in organic matter (SOM, **Map 6**), with correspondingly low effective cation exchange capacity (eCEC, **Map 7**), except in the Southern parcel where the eCEC is relatively favorable. Thus, WFR soils are consistently low in general fertility, since both SOM and eCEC are positively correlated with tree growth , soil nutrient content , nutrient cycling rates , and overall ecosystem productivity . Because of the appreciable distance to the ocean, soil salinity, typically inversely related to plant productivity (Corwin and Lesch 2005) is quite low (**Map 8**).

**Table 1.2.3. Dominant soil types in the WFR are fine textured, typically acidic, and isohyperthermic.**

| Key | Name |
|---|---|
| AeE | Fine, parasesquic, isohyperthermic Ustic Palehumults |
| HLMG | Very-fine, kaolinitic, isohyperthermic Rhodic Eutrustox |
| HnB, HoB | Very-fine, mix., semiact., nacid, isohyperthermic Typic Endoaquepts |
| KHMC,E | Very-fine, ferruginous, isohyperthermic Rhodic Acrudox |
| LoB,D,E | Very-fine, parasesquic, isohyperthermic Typic Palehumults |
| PYD,F | Fine, smectitic, isohyperthermic Typic Haplusterts |
| WpF | Very-fine, isotic, isohyperthermic Typic Haplohumults |

### *1.2.3.2. Hydrology*

Although there are several drainages across the area, only one named stream (Waimānalo Stream) actually flows through the Northern parcel (**Map 9**). Unnamed drainages abound, with the largest of these adjacent to the Nā Ala Hele Demonstration Trail (

Figure 1.2.3), but these watercourses are highly seasonal, and in years of average precipitation may not flow at all. Average annual rainfall (Figure 1.2.4) is 1066 mm (42 in), and is heavily concentrated between the months of November and February. Consequently, plants in the WFR show highly seasonal growth patterns, with some trees (e.g. *F. moluccana*) undergoing dry season dormancy and leaf loss. Because soils are well drained in most areas of the WFR (**Map 4**), drought stress presents a serious barrier to agricultural productivity, and most of the naturally occurring plants (whether invasive or native) show some degree of tolerance to seasonal drought. In areas where soils are not well drained, the lack of rainfall and limited extent of these areas means that there are no classified wetlands in the Reserve.


**Figure 1.2.3. Strong seasonality in rainfall patterns means that heavy rains, usually during winter months, may contribute to severe erosion problems in areas where access trail maintenance is inadequate (here, Nā Ala Hele Demonstration Trail).**

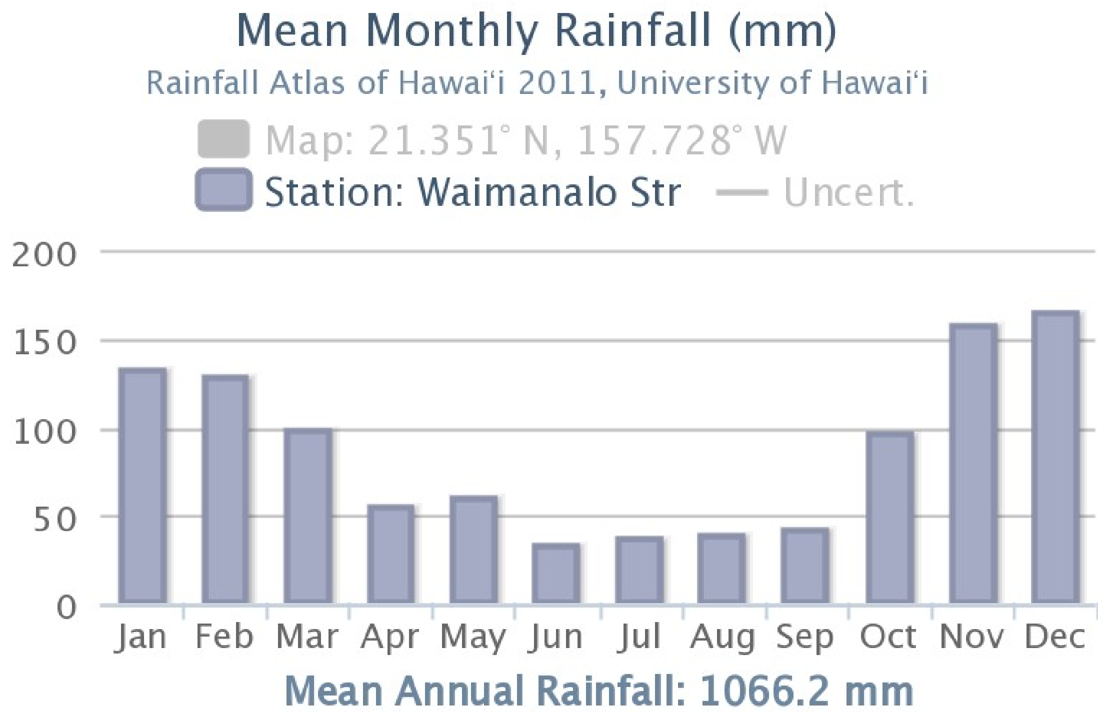



**Figure 1.2.4. Average monthly rainfall[2] for the weather station nearest to the WFR.**

### 1.2.4. Infrastructure

As a State of Hawaiʻi Forest Reserve, infrastructure development in the WFR has been highly constrained. Only two categories of infrastructure exist, the Nā Ala Hele trail system, and the Department of Agriculture irrigation water supply (**Map 10**). The trail system includes the Waimānalo Ditch Trail, which follows the path of a now-removed irrigation ditch from the East side of the parcel to its center, and the Demonstration Trail, which bisects the parcel Southeast to Northwest (**Map 10**). The Ditch Trail is a foot path, equestrian trail, and cycling route, while the Demonstration Trail is large enough to accommodate a 4x4 vehicle (**Fig. 1.2.6**). Trails are maintained in part by Nā Ala Hele and partially by user groups, including a formally organized equestrian association the informal cyclist demographic. It is important to note that these trails are the only publicly accessible equestrian trails on the entire island of Oʻahu, and that the equestrian groups who use it are therefore extremely protective of the status quo.

[2] http://rainfall.geography.hawaii.edu/interactivemap.html


**Figure 1.2.5. Nā Ala Hele administration covers a foot and equestrian path called the Ditch Trail (left), and a 4x4 road called the Demonstration Trail. Both trails are heavily used by equestrian groups, cyclists, and hikers, while motorcycle or ATV use is prohibited (right).**

The Hawai'i Department of Agriculture maintains an irrigation water supply at the western side of the WFR. This system enters the WFR as an open concrete ditch covered by a metal grate, and then transitions to a closed pipe that exits the Reserve at Waikupanaha Street. Water use laws prohibit drawing irrigation water directly from the ditch or pipe, rather, irrigation water in Waimānalo Valley can only be used after it exist the Waimānalo Irrigation Reservoir. For locations adjacent to the WFR, this means that water must be piped back from the reservoir to the source through a secondary system. A 10" irrigation pipe along Waikupanaha Street would be available as an inlet on the Southwest side of the property, while a 6" irrigation pipe on Mahiku Place would be available as an inlet at the Northeast (**Map 10**).

## 1.3. Land use and risk factors

### 1.3.1. Land use districts

The majority of the WFR (350.9 acres) is State of Hawai'i Conservation District, designated as the Resource subzone (**Map 11**). The remaining 132.7 acres are in the Agriculture Land Use District (LUD) (**Map 11**). Permissible management activities in the Conservation District vary depending on subzone, but the Resource subzone is the least restrictive (**Appendix B**). Private landowners may pursue certain management activities compatible with the overall vision for Conservation District lands under the directive of a Conservation District Use Permit (CDUP) (acquired after submission and approval of a Conservation District Use Application (CDUA) (**Appendix B**)). Because the WFR is owned by DLNR DOFAW, however, management activities in the Conservation District may be pursued with a Concurrence from the Office of Conservation and Coastal Lands (OCCL). The typical CDUP acquisition process may be largely avoided.

### 1.3.2. Land use patterns

#### *1.3.2.1. Current land use*

The Waimānalo Valley community adjacent to WFR is strongly agricultural, with a majority of businesses involved agricultural production, nursery operations, and other land-based activities. Most of the State and privately owned parcels that border the WFR are in the Agriculture LUD (**Map 11**), although the official State of Hawai'i Agriculture Land Use Map (**Map 12**) has not yet been updated to include the latest agricultural subdivision. The most common agricultural activity near the WFR is nursery production. Most of the agriculture lots are relatively small, so producers maximize their return on investment by concentrating on high-value nursery products rather than lower value agricultural commodities. Nursery production is ill-suited for the WFR itself, however, because of steep slopes, uncertainty in water infrastructure (§1.2.4, §3.2), and logistical constraints. Nurseries typically require substantial built infrastructure, which is generally not compatible with land use rules in the Conservation District (**Appendix B**). The other major land use in the WFR is noncommercial recreation, including hiking, mountain biking, and equestrian use of the DLNR Nā Ala Hele trails. The Ditch Trail is open to all three user groups, but the Demonstration trail, due to its steep slopes, is restricted to cyclists and hikers. Hunting occurs in the forest reserve, but hunting rights and accessibility are outside the scope of this FMP.

#### *1.3.2.2. Historical land use*

Although current vegetation cover completely masks prior land uses, the Waimānalo Valley was historically dedicated to agricultural production. Prior to European arrival, Waimānalo Valley supported some traditional agricultural, although the extent of taro fields may have been limited due to the relatively dry conditions (Handy *et al.*, 1972). Some evidence exists of an extensive taro field system surrounding the base of the mountains at the back of the valley (Handy *et al.*, 1972). Sugar cultivation occurred in the valley during the first half of the 20$^{th}$ century, largely erasing signatures of original Hawaiian agriculture; by 1972 the dominant land use was ranching (Handy *et al.*, 1972). The Waimānalo irrigation ditch (current location of the Ditch Trail on the Eastern side of the WFR) transported water initially to sugar plantations and then to ranches before it was replaced with reservoir system in 1993 (HDOA PSF No. 970D-369).

### 1.3.3. Risk factors

#### *1.3.3.1. Natural disasters*

The WFR is in an area that has been designated low fire risk (**Map 13**, **Appendix D**); relatively low understory fuel loading, limited amounts of forest floor litter, seasonal streams, and proximity to fire fighting water all contributed to the low fire risk. Flooding risk is either minimal (FEMA X zone) or low but undetermined (FEMA D zone) (**Map 14**); portions of the WFR most likely to experience flooding damage are the Demonstration Trail (**Fig. 1.2.4**) and the Mahiku Place access, which crosses a seasonal stream that often floods after winter rains.

#### *1.3.3.2. Illegal activities*

The chief existing problem with illegal activity in the WFR is motorcycle use on Nā Ala Hele trails. Motorcycles disturb the authorized trail users, and are not compatible with watershed conservation because they cause serious erosion problems. Motorcycle use is encouraged on other Nā Ala Hele trails elsewhere on Oʻahu. Illegal disposal of landfill items, from household appliances to common rubbish to entire cars, is an ongoing problem in many areas of the WFR, although this problem largely involves material dumped in the forest many years ago rather than an epidemic of new illegal waste disposal.

Although not currently an issue in the WFR, theft and vandalism are serious problems for existing agricultural producers in the Waimānalo Valley. Thieves steal agricultural equipment, nursery infrastructure, potted plants, and fruit. Mitigating theft losses must be a priority for any agroforestry project, and cannot be accomplished without an active, positive relationship with the community.

#### *1.3.3.3. Avoiding pest and pathogen introduction*

Producing the large numbers of seedlings required to implement this management plan will require a variety of nursery sources both on Oʻahu and from neighbor islands. In particular, many of the timber species are produced en masse only by the State Tree Nursery in Kamuela, Hawaiʻi Island, which is also the chief supplier to many Oʻahu nurseries. Although most fruit tree species can be produced on Oʻahu, and even within the

Waimānalo Valley, large-scale nurseries that produce native Hawaiian plant species are located on Maui and Hawaiʻi as well as Oʻahu. The geographic diversity of nursery sources calls for a standardized phytosanitation protocol to minimize the likelihood of importing invasive species. Some invasive species, including the Coqui frog, are restricted to neighbor islands and their introduction to Oʻahu would be disastrous. Other species, such as Australian tree fern, may already exist on Oʻahu, but should never be planted. The precise form and content of the phytosanitary protocol for the Waimānalo Forest Reserve is beyond the scope of the present plan, but examples exist from State and Federal agencies, for example from DLNR DOFAW[3], or the phytosanitary procedures of Hawaiʻi Volcanoes National Park (HAVO), which may be obtained from the Natural Resources Director at HAVO. In broad terms, contractors, vendors, community groups, or individuals who seek to implement any specific forest management regime derived from the current plan would be required to conform to phytosanitary standards to avoid importation of invasive species (with the exception of those already present (see §1.2.2)) to the WFR.

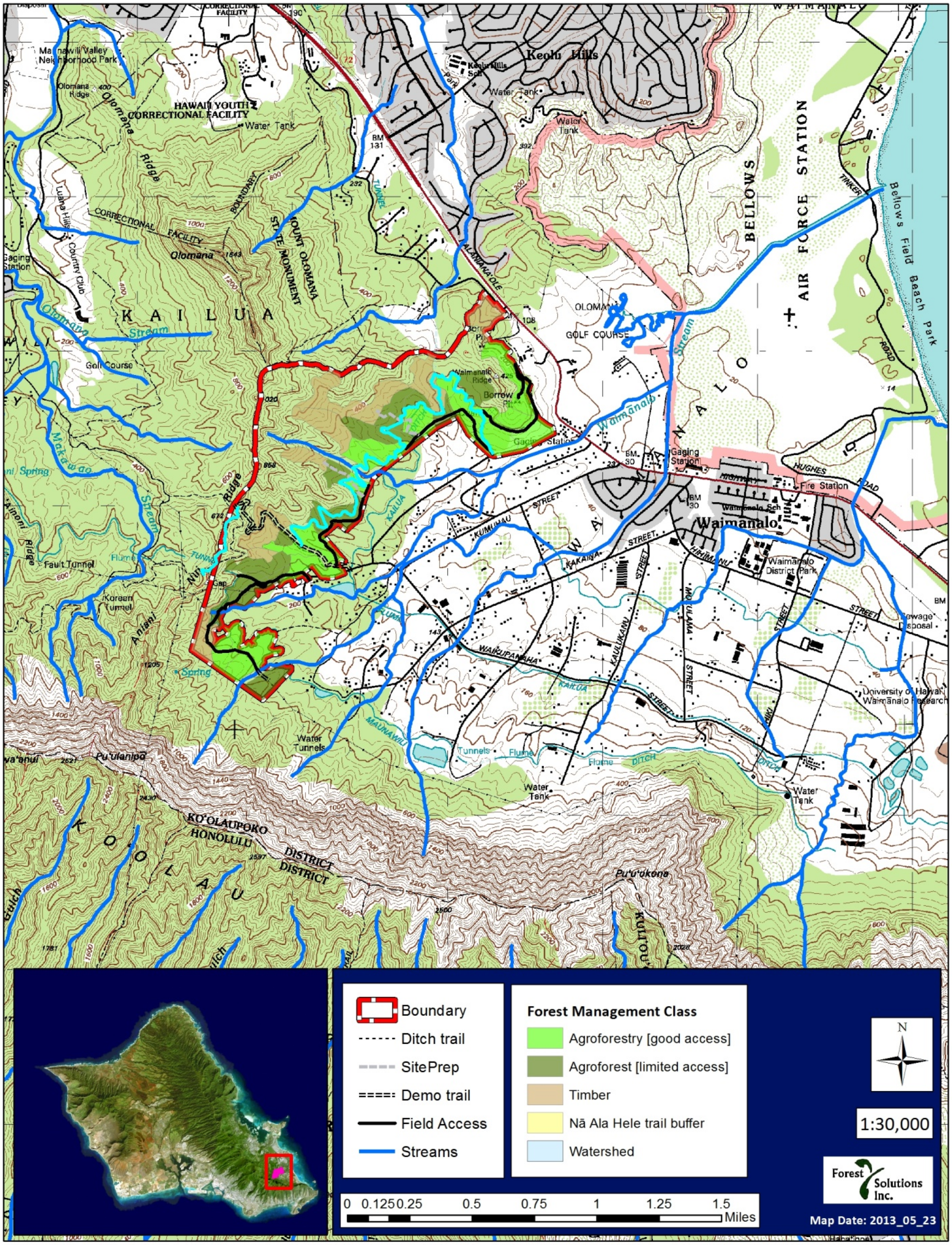
## 1.4. Forestry and agroforestry literature review

Optimum silvicultural and productivity of tree-dominated systems depends strongly on species-site interactions, whether for traditional timber production or multi-level agroforestry. Due to the large number of species presented in this plan and the unforeseeable diversity of project plans that may be submitted by contractors or community groups, it is not practicable to list the detailed elements, e.g. planting densities, soil preparation, optimum fertilizer prescriptions, horticultural and harvesting schedules for particular silvicultural regimes. Rather than review information collected from primary sources, much of which may not be useful to the ultimate project managers, silvicultural prescription information is included in this FMP in one of two ways. First, literature sources are cited in-line where relevant to the five model systems (§4) used to develop the overall plan cost assessment. The information is either included directly in the text of the plan, or implicitly within financial models, species tables, or in other forms. Second, the sources of information used to develop this plan are provided as an electronic appendix (.zip archive, "*Silvicultural Literature Review, Waimānalo, 2013.zip*") organized by management subject, including site assessment, forest management type, and species. All information used either in the development of this plan or included in this appendix is hereby attributed to its original source. For citations in-line, sources may be found in the References (§8); for literature, source information is included as a component of the accumulated .pdf documents.

[3] http://www.state.hi.us/dlnr/dofaw/hortweeds/

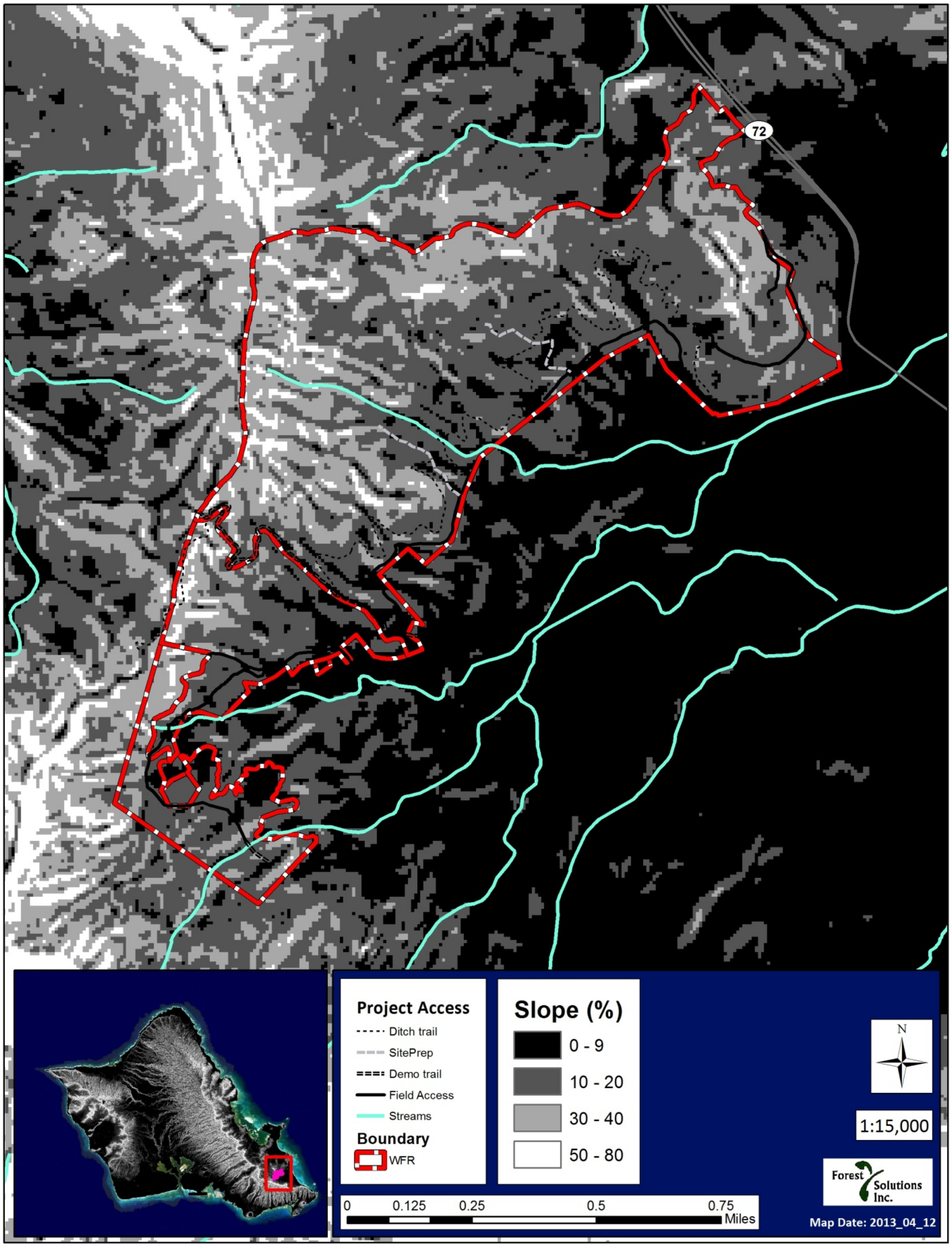
## 1.5. Map plates

Map 1. **Topographic map.**



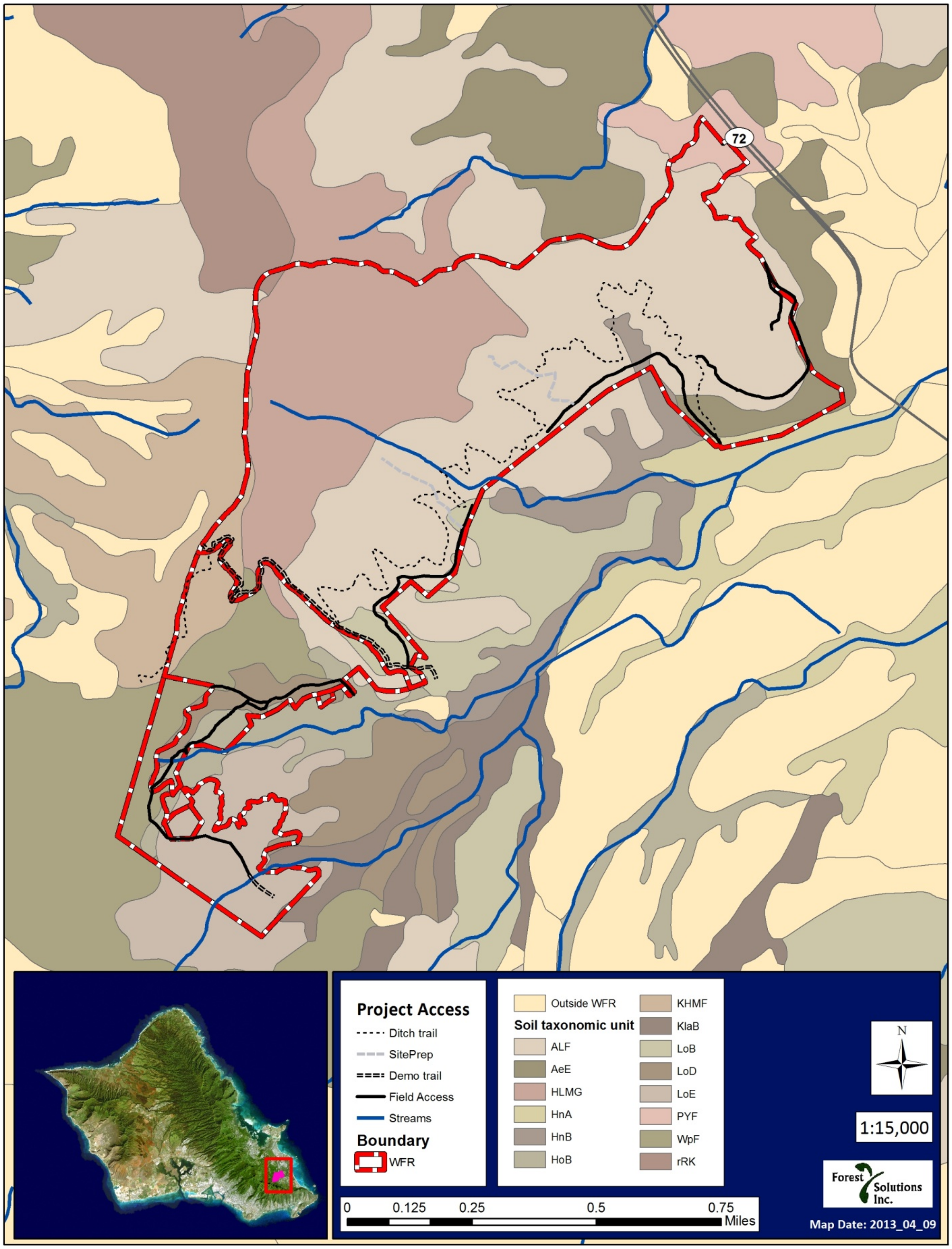

Topographic map of the WFR in the context of Waimānalo Valley and the surrounding area of windward Oʻahu.

Map 2. **Slope.**



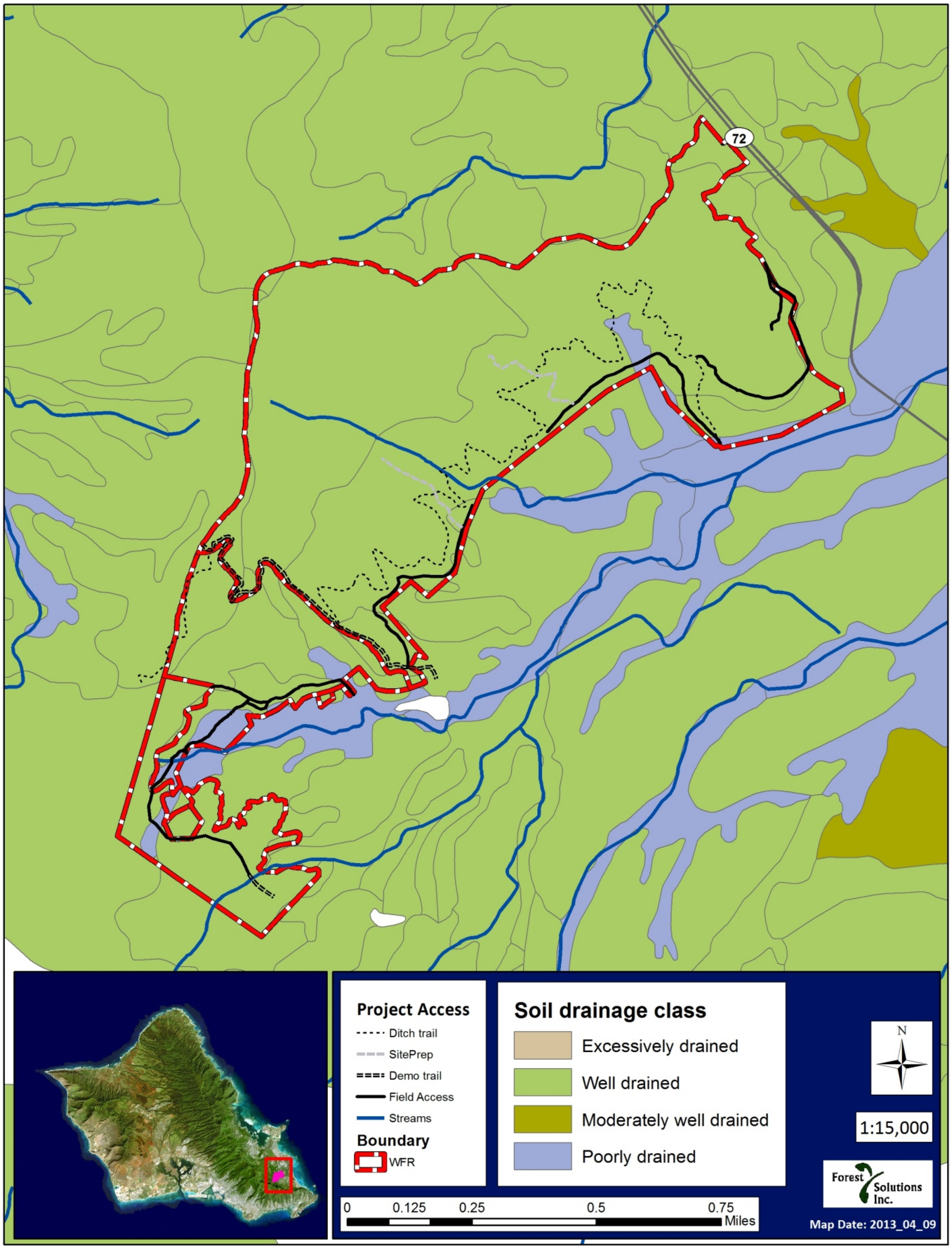

Slopes in the WFR vary from flat (0%) to in excess of 80%. Steep areas are reserved for watershed conservation management.

Map 3. **Soil classification and texture.**



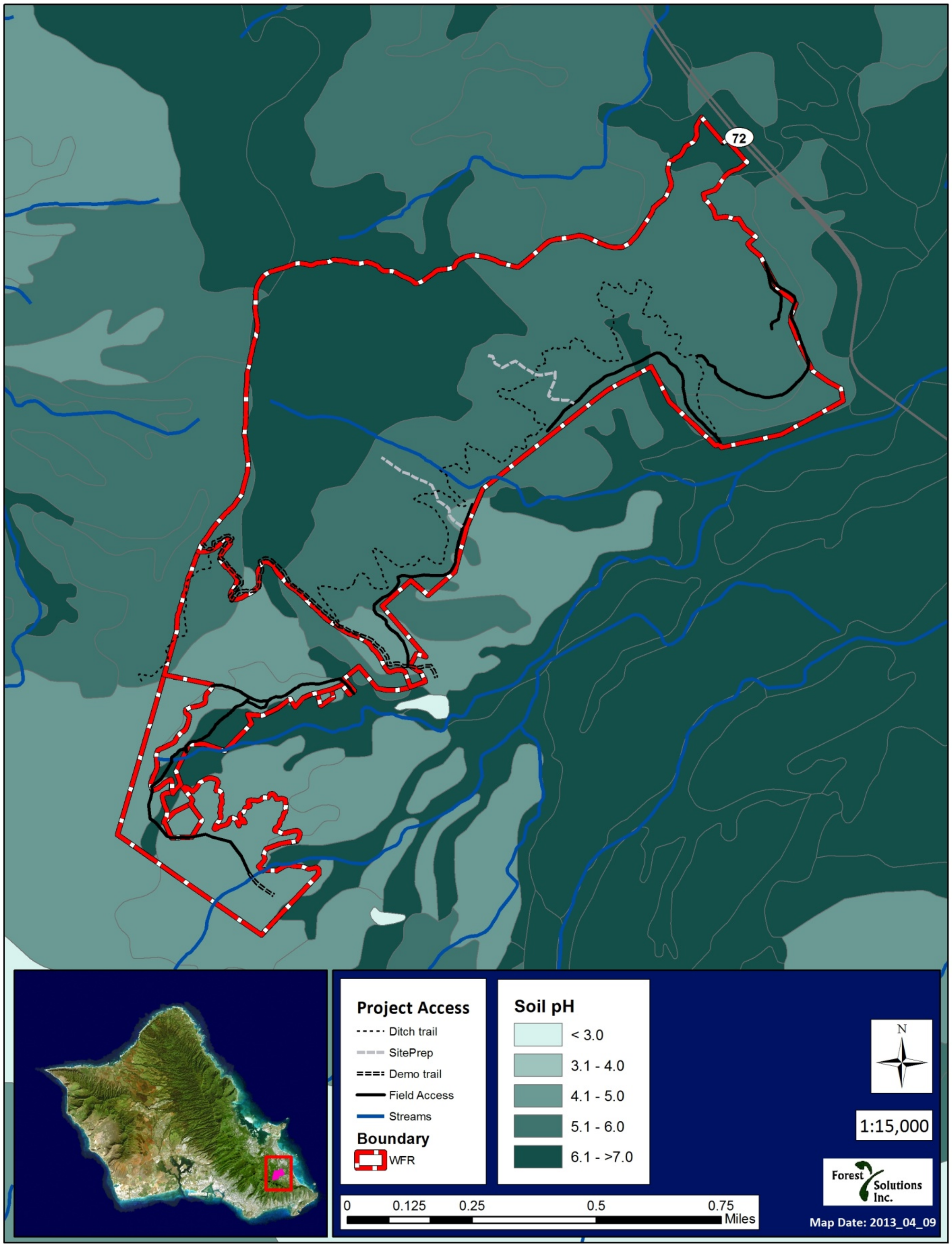

Soils in the WFR fall into seven broad classes, and are typically fine-textured, well drained, acidic substrates.

Map 4. **Soil drainage.**



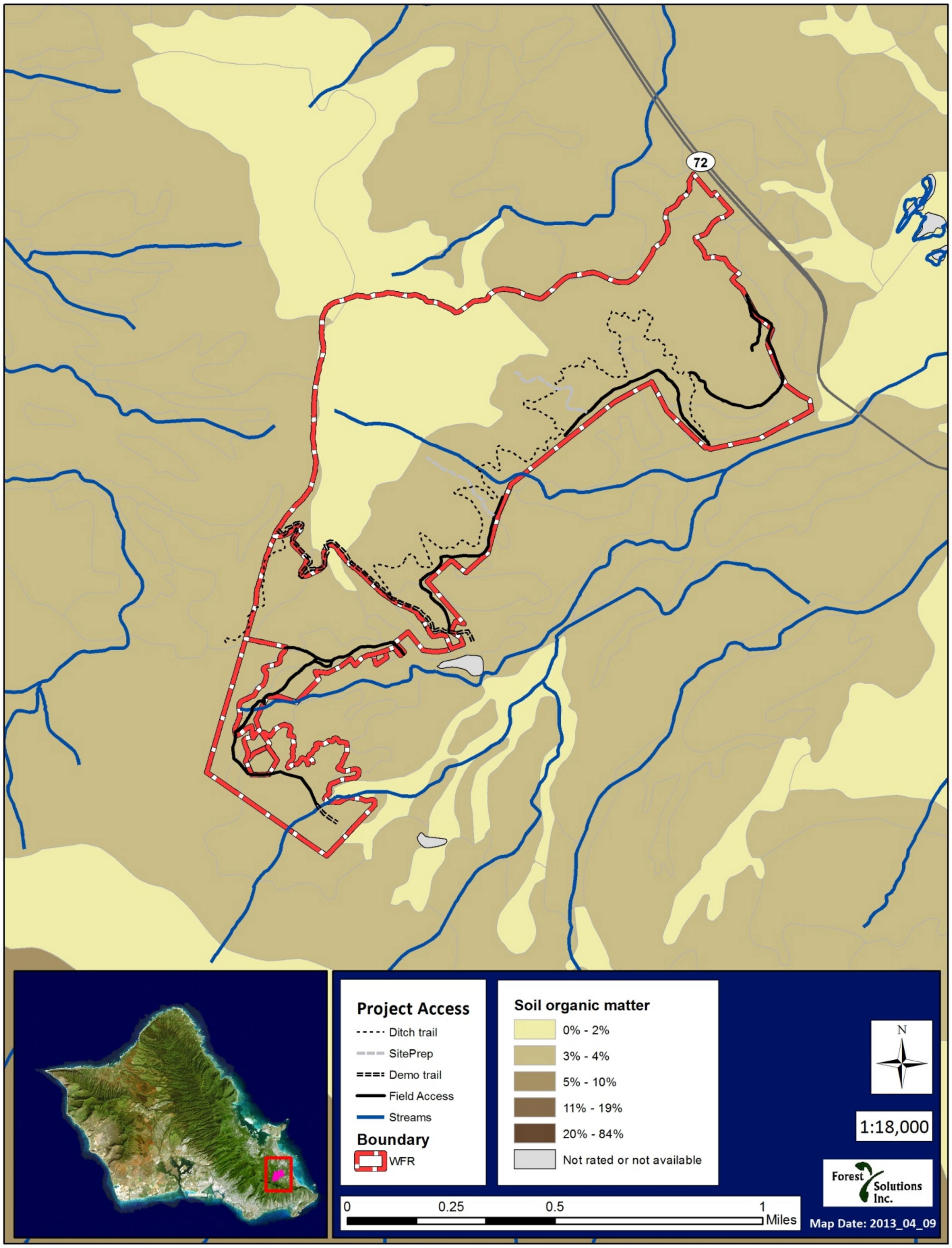

With the exception of some riparian zones, soils are well drained.

Map 5. **Soil pH.**



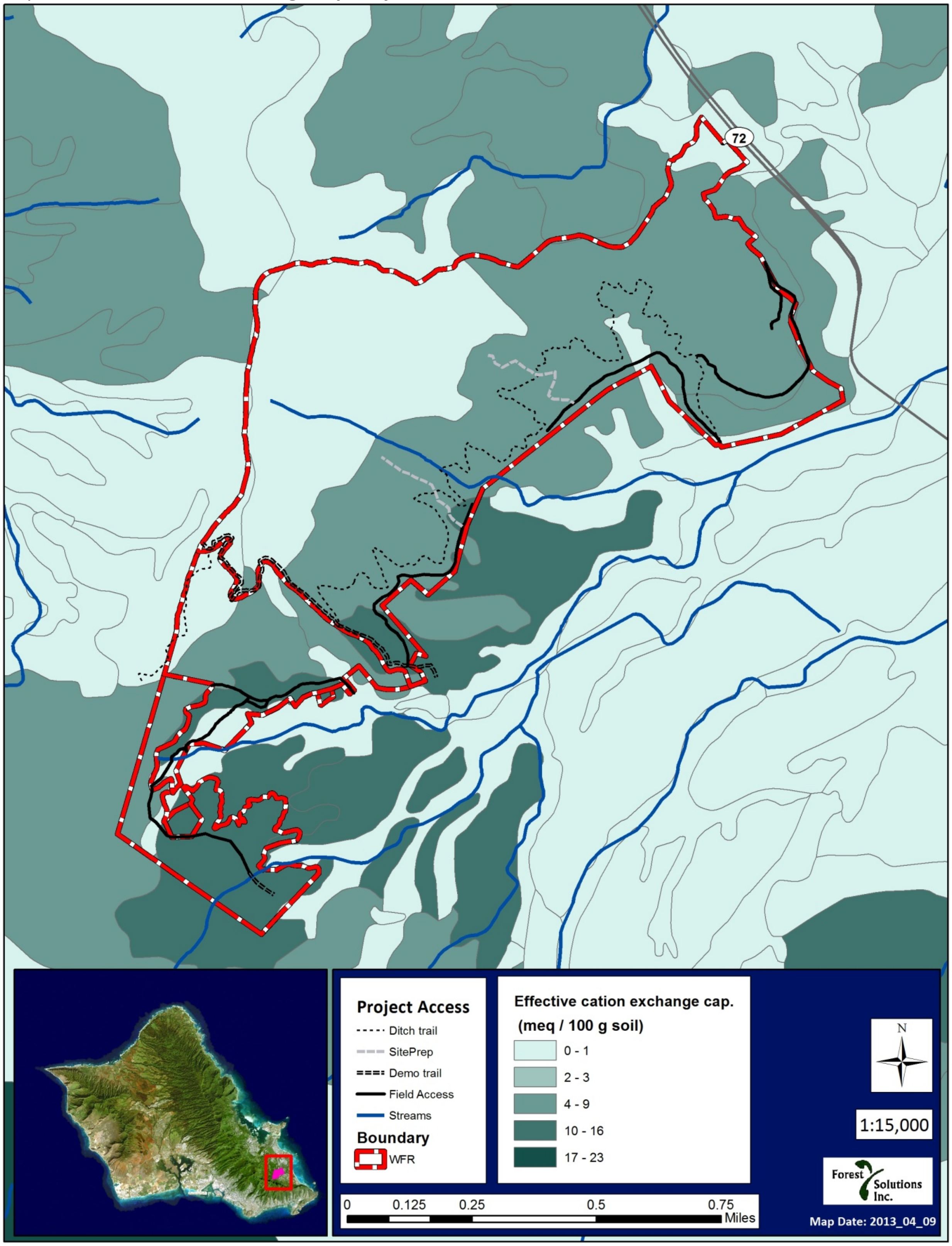

Consistently acidic soil pH characterizes WFR soils.

Map 6. **Soil organic matter.**



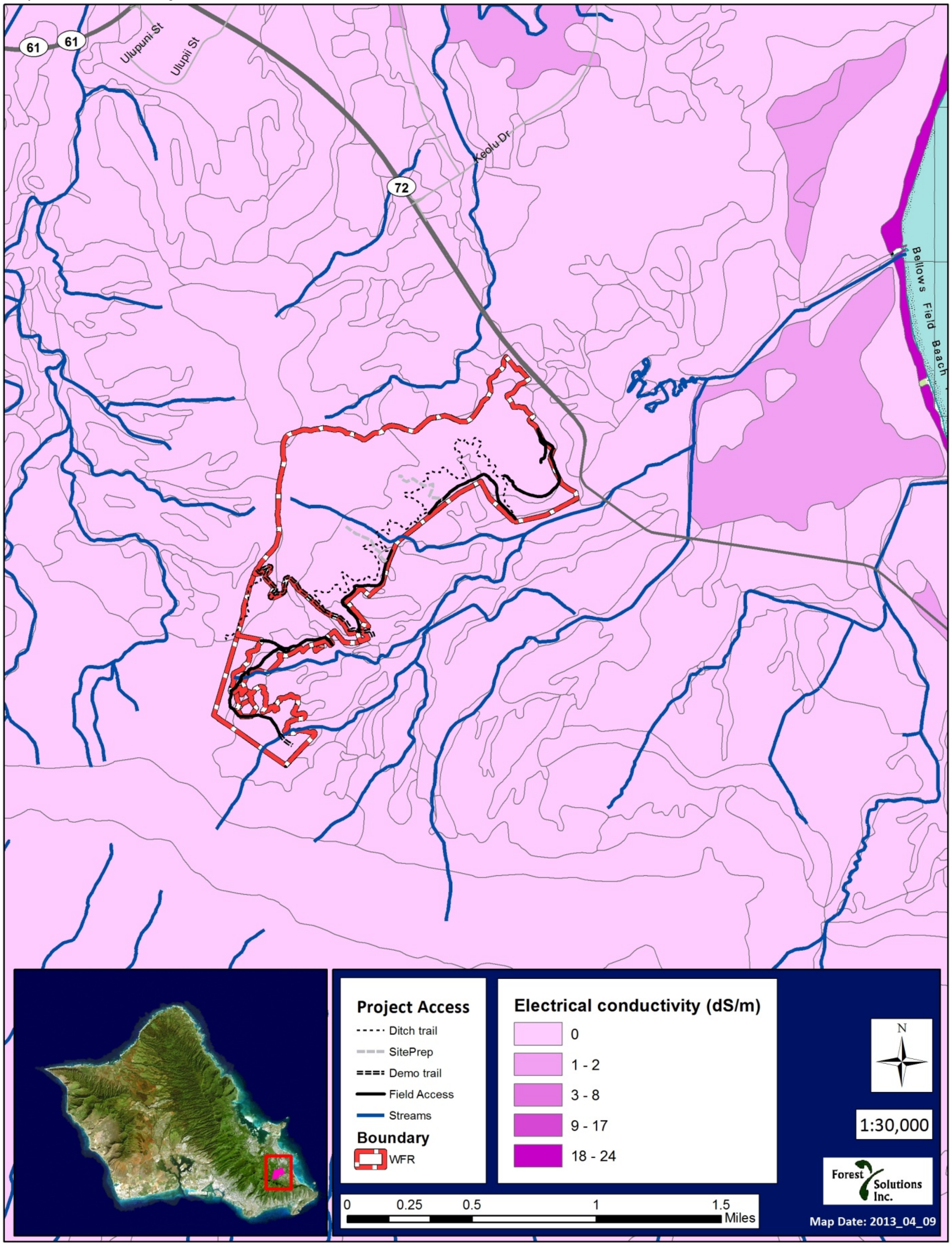

High decomposition rates of leaf litter and wood debris result in low soil organic matter (SOM) levels throughout the WFR.

Map 7. **Effective cation exchange capacity.**



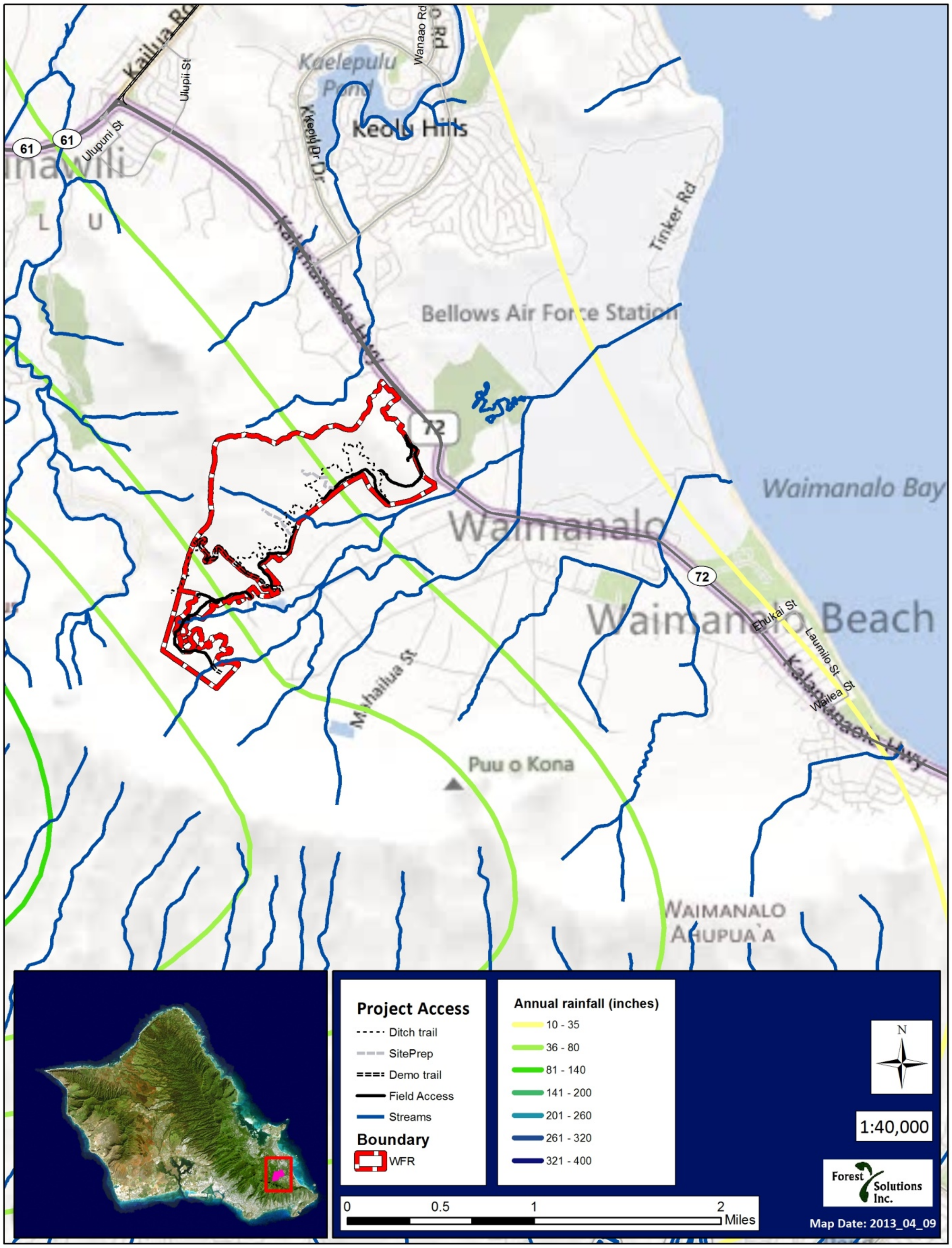

As an integrated measure of overall soil fertility, effective cation exchange capacity (eCEC) is relatively low for most soil types in the WFR.

Map 8. **Soil salinity.**



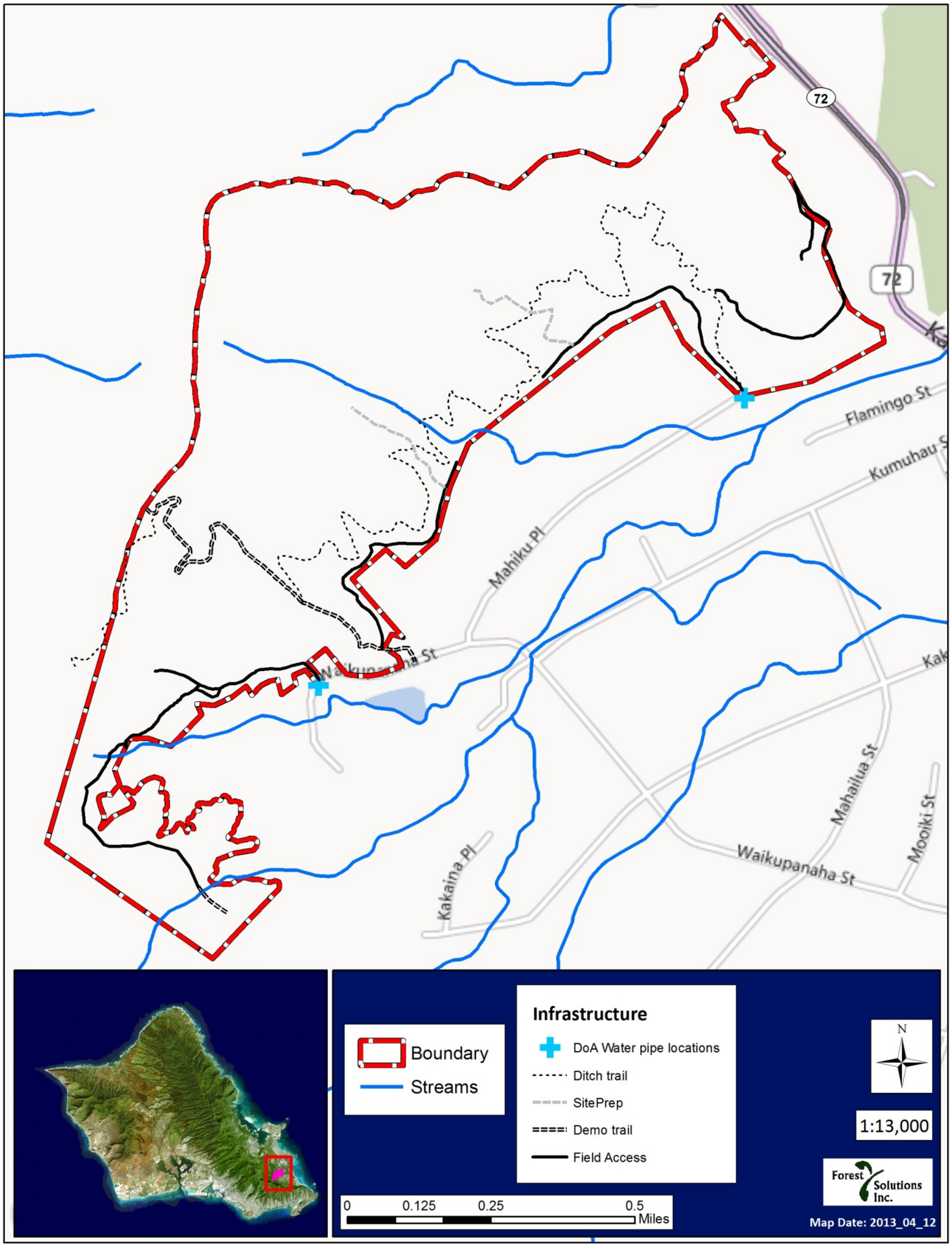

Soil salinity, as measured by electrical conductivity (EC) is low, suggesting that most soils are not compromised by excess salt content.

Map 9. **Annual rainfall isohyets.**



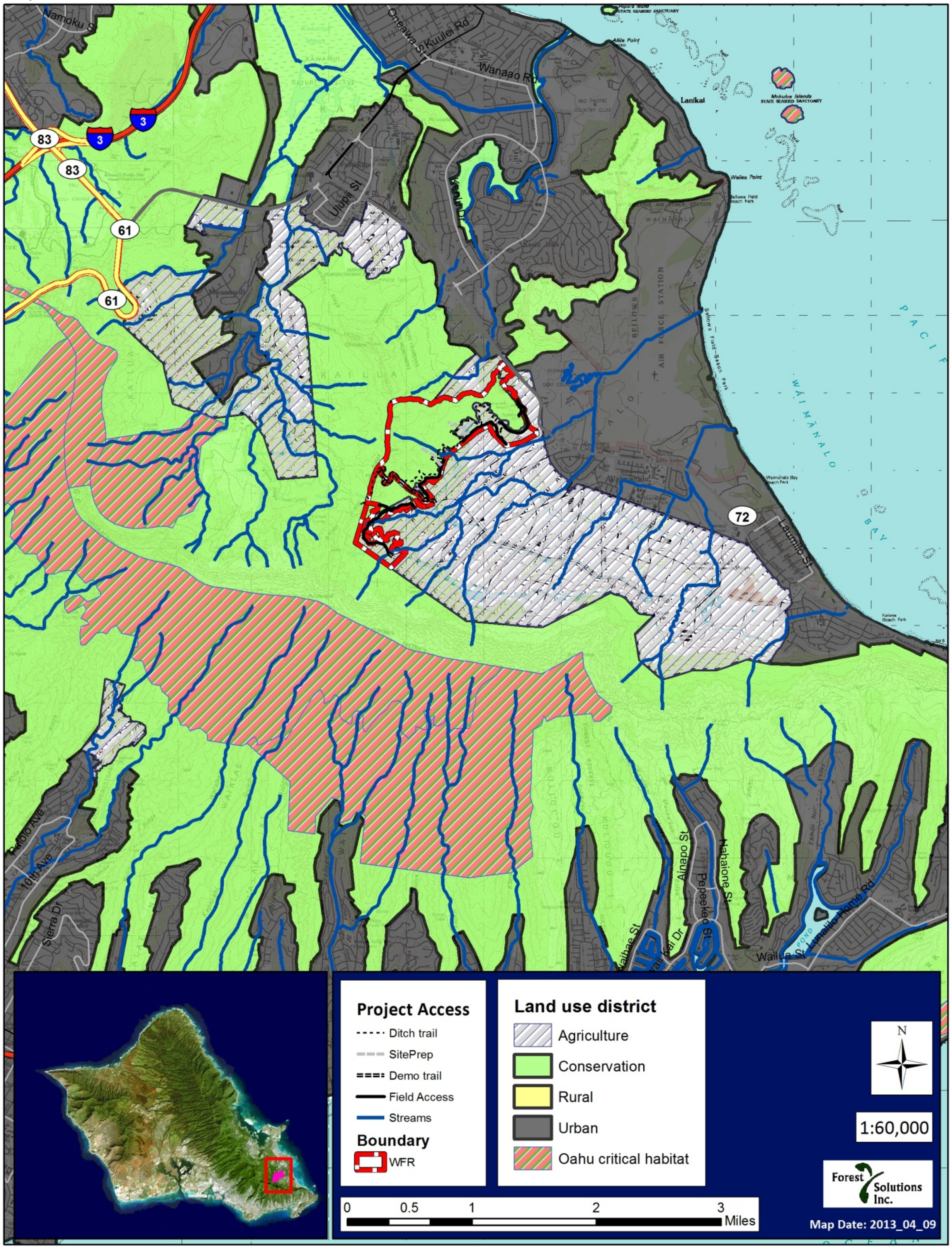

Annual rainfall in the Waimānalo Valley varies from 36 inches (900 mm) to 80 inches (2000 mm).

Map 10. **Trail infrastructure.**



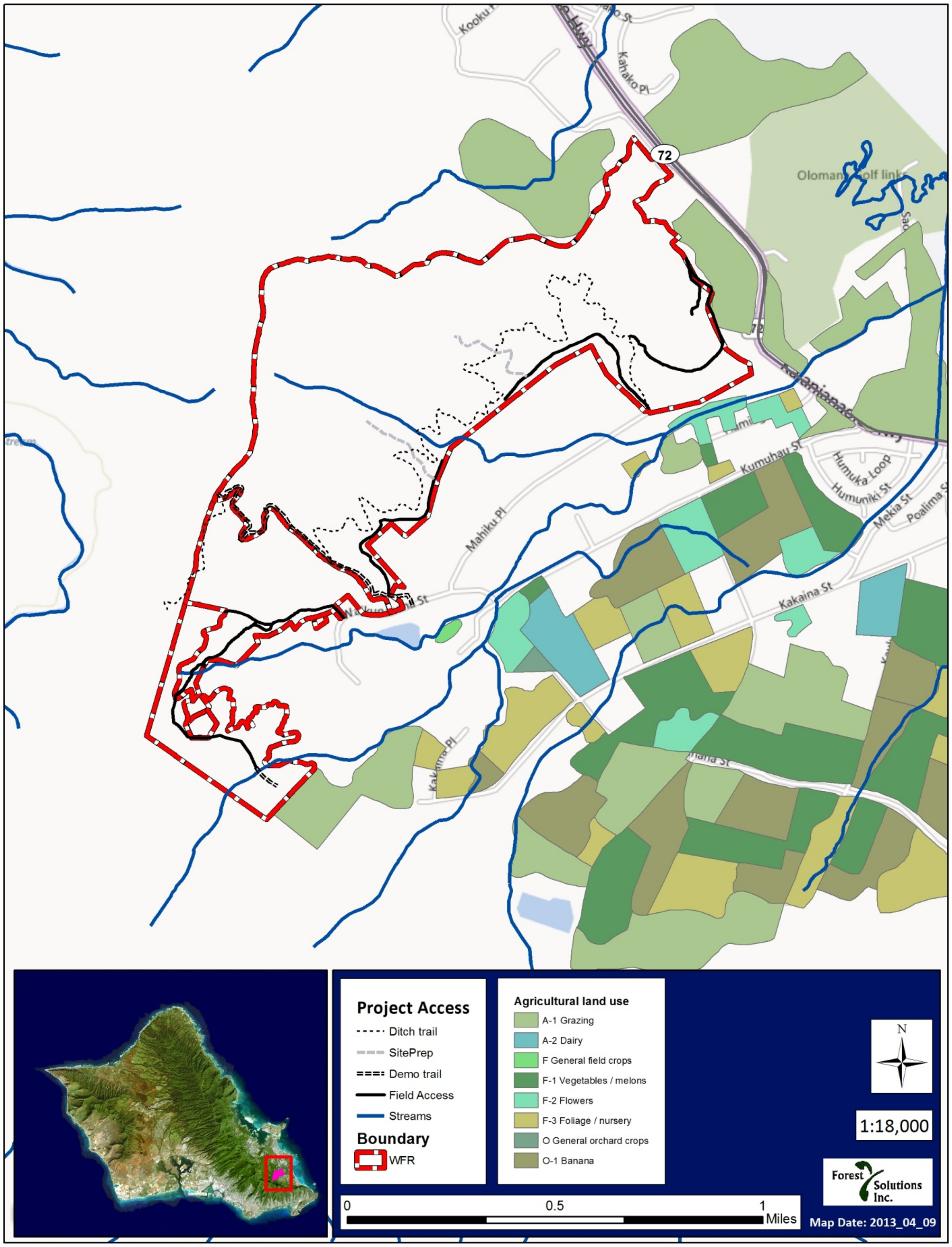

Infrastructure in the WFR is limited to Nā Ala Hele trails and Department of Agriculture irrigation ditch structures.

Map 11. **Land Use Districts.**



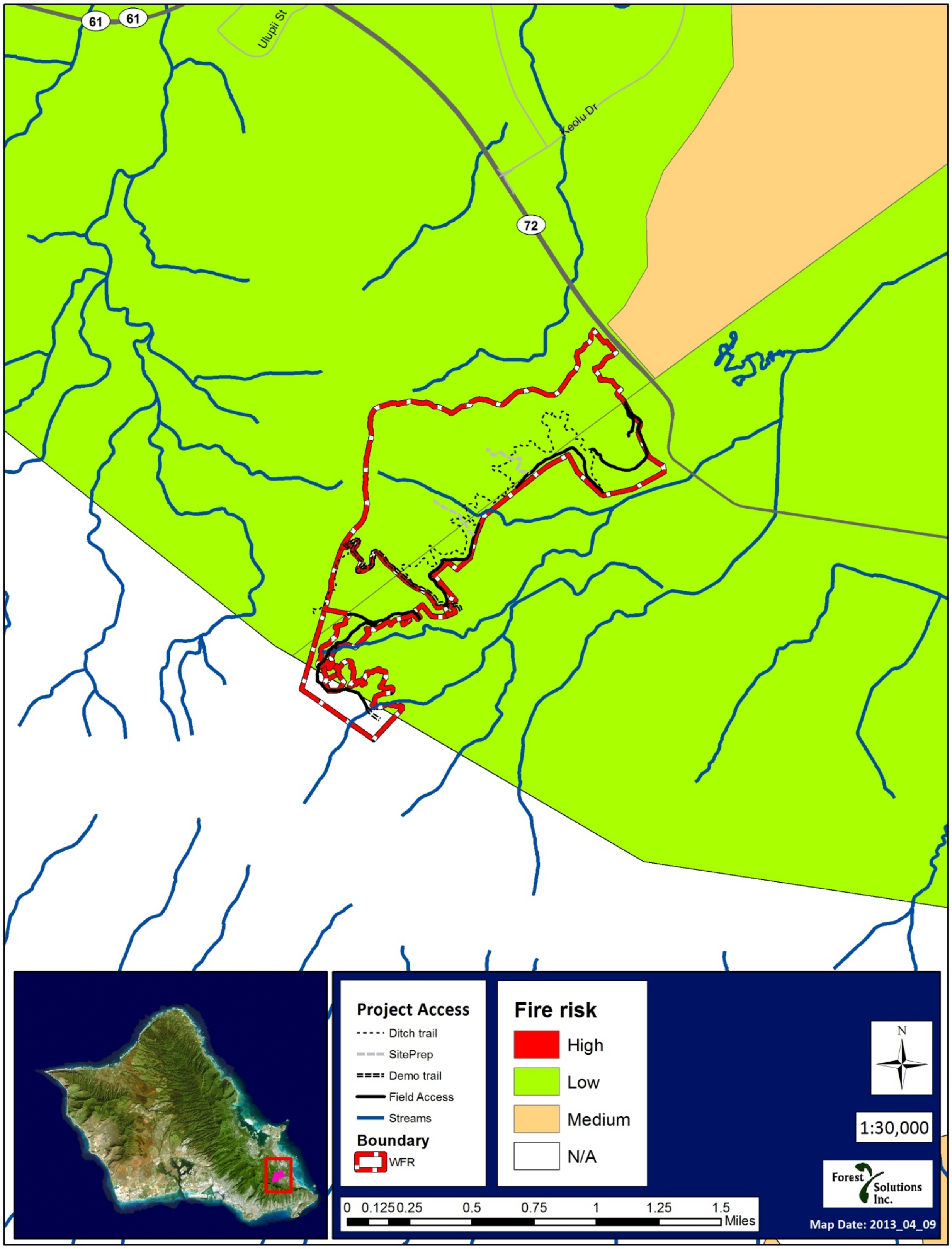

Two LUD are represented in the WFR, Conservation District (subzone resource) and Agriculture.

Map 12. **Adjacent agricultural land uses.**



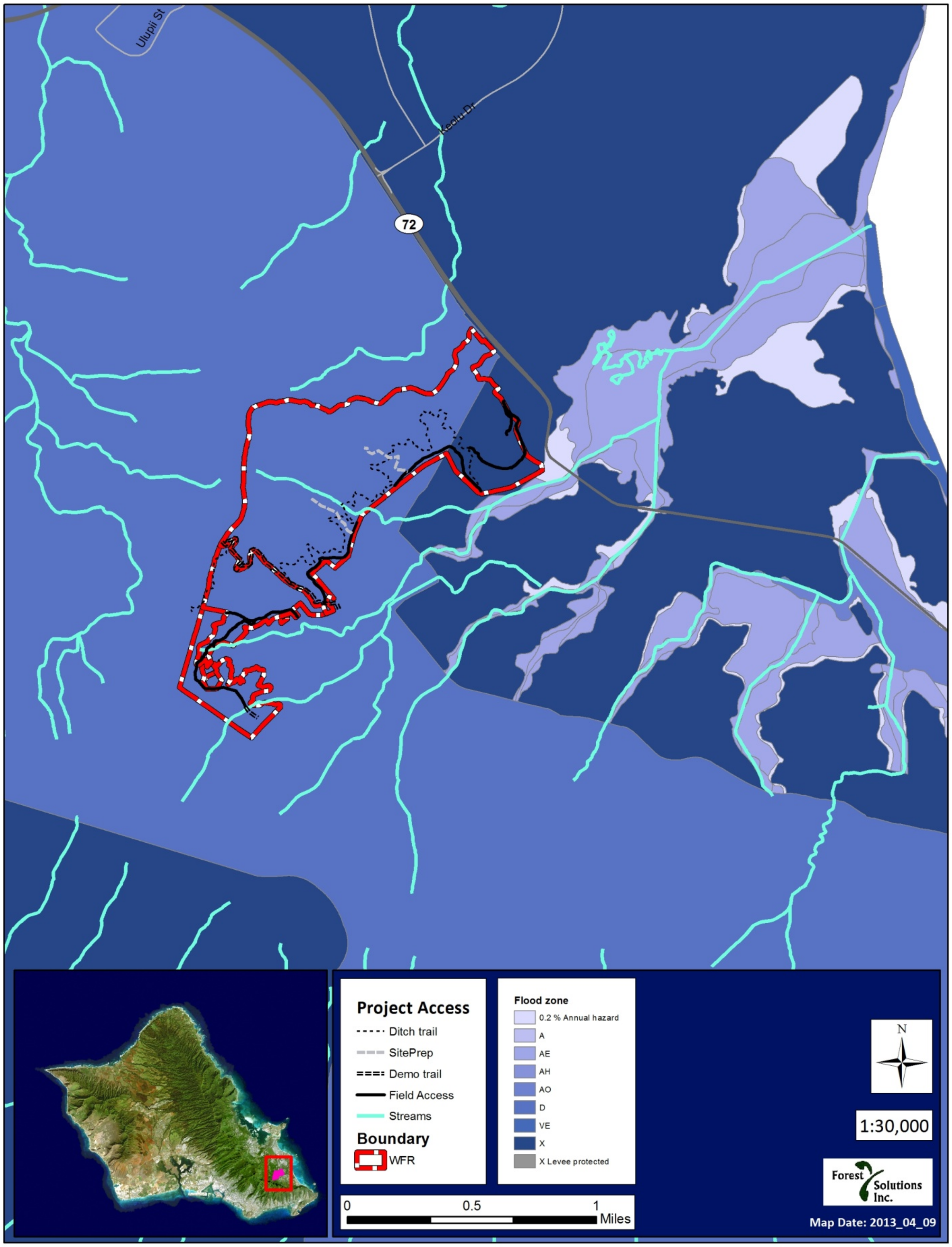

Adjacent agricultural land uses include nursery, fruit production, and grazing.

Map 13. **Fire risk classification.**




The entire WFR is located in an area with low fire risk.

Map 14. **FEMA flood risk zones**




FEMA flood risk zones X (negligible risk) and D (low but undetermined risk) are present in the WFR.

# 2. Land Classification

## 2.1. Forest management classes and compartments

Management activities in the WFR agroforestry project are prescribed within a structure of forest management classes (FMC), which are defined as areas that share a management type, species composition, current overstory structure, and potential project outcome. For the WFR, a total of five FMC are designated, including (1) watershed, (2) timber, (3) intensive agroforestry, (4) moderate agroforestry, (5) and access (Figure 2.1.1). Boundary delineation emerges from several criteria, including abrupt slope changes, shifts in remotely sensed vegetation cover, extant access routes, and current State of Hawai‘i Conservation District subzone boundaries. At the smallest scale, the four TMK that constitute the project area are divided into compartments, also referred to as fields in the context of agroforestry. Areas assigned to a particular FMC indicate that the prescribed activities are suitable for the compartment and may be most successful there. Assignment of a FMC does not mean that a given prescription must be applied to the entire compartment. Rather, implementation will be contingent on funding availability, stakeholder interest, and community input.

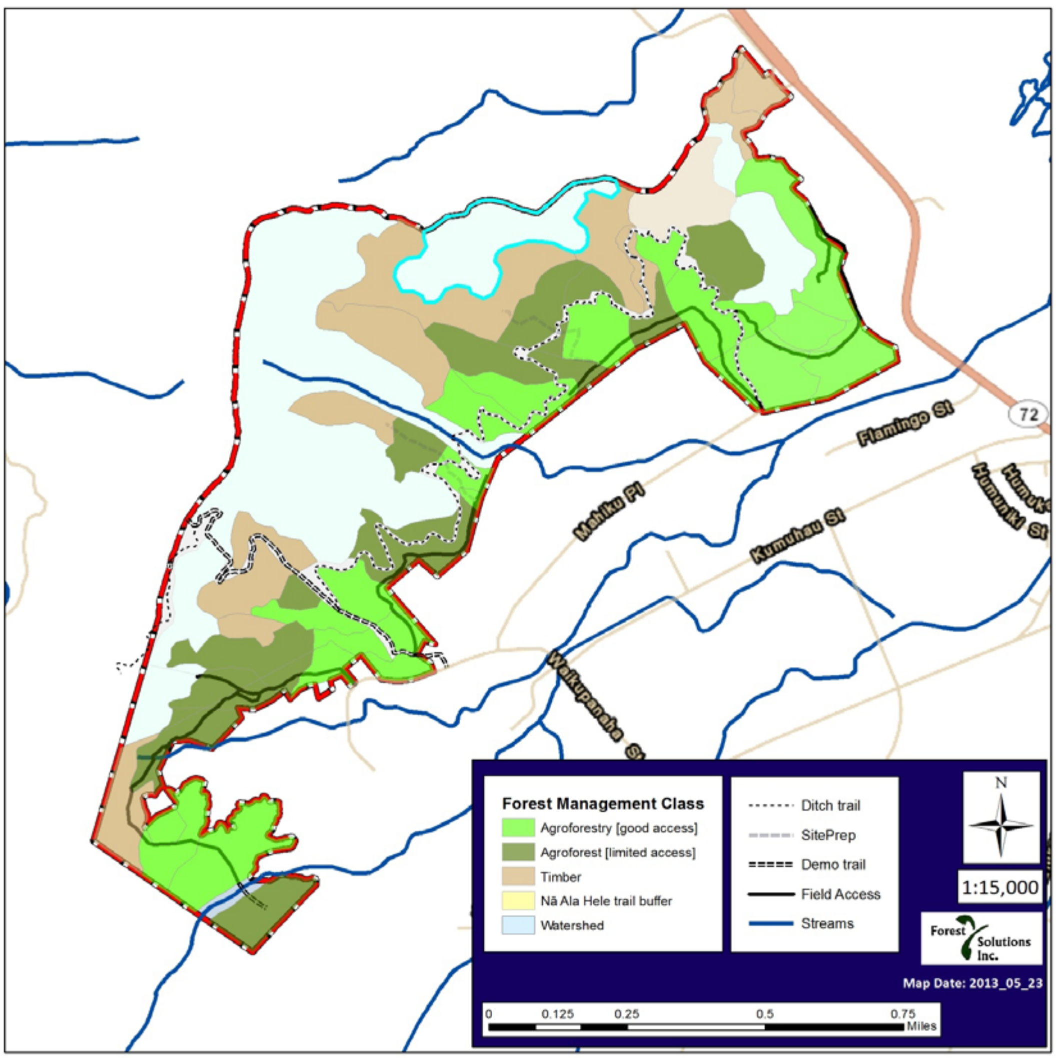



**Figure 2.1.1. FMC in the WFR place agroforestry activities at low elevations (greens), timber at intermediate elevations and slopes (beige). Watershed protection areas (light blue) are reserved for the steepest high-elevation slopes. Areas within each FMC—compartments (grey outlines)—represent the basic project management units.**

### 2.2. Watershed (174.3 acres)

Preserving vegetation cover on the steeper slopes of the WFR, which exceed 80% in some areas, is critical to preventing erosion, avoiding downstream siltation, and maintaining ecosystem health in streams and the ocean (Atkinson and Medeiros 2006). Erosion of silty clay loam soils may occur with relative ease on bare slopes greater than (10%), and is virtually assured on bare slopes greater than (20%). Consequently, areas within the WFR that contain extreme slopes between 40% and 80% are reserved for watershed protection (WP), wherein overstory management will occur only within strict parameters (§3.3.1). Management activities will be restricted to invasive weed control and replacement of non-native vegetation with native Hawaiian species whose root systems equal or exceed the ability of the current vegetation to prevent erosion.

### 2.3. Timber (75.3 acres)

At intermediate slopes between 20% and 40%, the WFR is suitable for timber applications (TR); timber compartments are relatively inaccessible, which does not favor mixed agroforestry. Timber management activities include site preparation, tree planting and maintenance, monitoring, and eventually low-impact selection harvesting should a supportive market environment exist.

### 2.4. Access-intensive agroforestry (119 acres)

Areas of the WFR with slopes less than 20%, that are adjacent to current or proposed access routes, and that are appropriately positioned for irrigation, are classified as intensive agroforestry (IA). Land use envisioned for these areas includes mixed plantings of multi-use overstory species with higher value understory plantings. Typical species combinations in such systems benefit from irrigation, and all require substantially more management activity than timber. Establishing intensive agroforestry systems will be contingent on stakeholder support, grant funding opportunities, and community involvement. The types of management activities that occur in IA compartments will include site preparation, tree planting of overstory and understory species, irrigation infrastructure deployment, orchard maintenance, monitoring, harvesting of fruits or nuts, and selective timber harvesting.

### 2.5. Moderate-access agroforestry (93.2 acres)

Certain compartments on shallow slopes (<20%) are suitable for fruit or nut trees, but have limited accessibility, potential for irrigation, or both. Resource-intensive mixed agroforestry plantings are less likely to thrive without water and regular management, but single-species plantings, isolated single-tree plantings, or community-driven projects that have minimal management constraints are well suited to these areas. Management activities would be analogous to §2.4, excluding irrigation deployment.

### 2.6. Importance of continuous forest cover

Across all FMC (§2.2-§2.5), it must be emphasized that the most fundamental objective for every management regime, both during the establishment phase and as a result of any activities, must be maintenance of continuous forest cover. The reason that the WFR was established as a forest reserve was to safeguard the Waimānalo watershed, and this can only be accomplished with an intact forest. As forestry and agroforestry projects are established, local forest density may temporarily decrease from its present value, but model prescriptions (§3) have been drafted in this FMP specifically to retain adequate forest cover for watershed protection. These model prescriptions are also designed to ensure that total forest cover is restored in short order, and that a completely intact forest is achieved within the rotation length of each proposed system.

## 2.7. Access

The physical area of the access FMC spans all of other FMC; this intersection requires careful planning from multiple perspectives, including community relations, State of Hawai'i land use district guidelines, construction standards, erosion mitigation strategies, and theft minimization. The access FMC can be conceptually divided (**Fig. 2.2**) into extant access (comprising DLNR Nā Ala Hele Ditch and Demonstration trails) and proposed access (including long-term Utility Task Vehicle (UTV) routes for agroforestry projects and temporary paths created during timber and agroforestry site preparation).

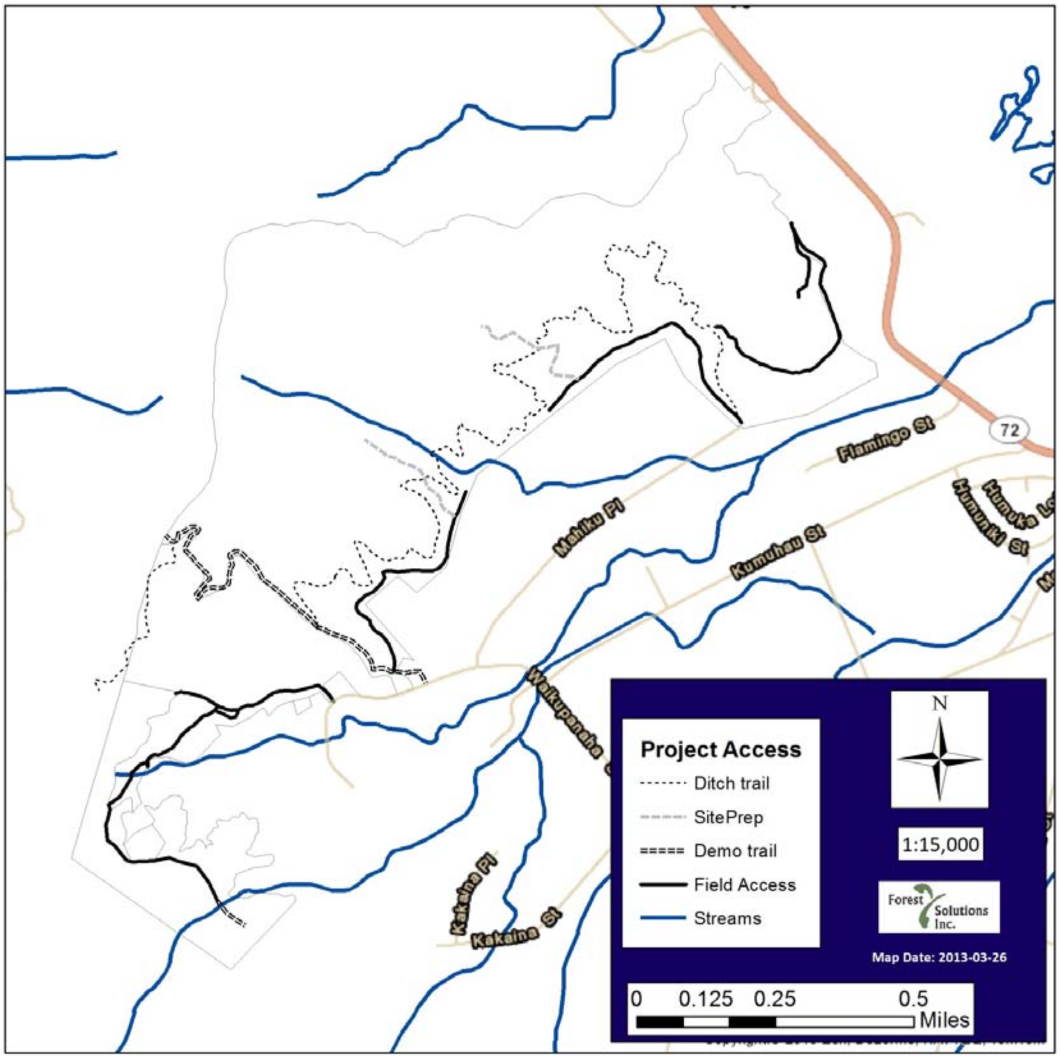



**Figure 2.7.1. Network of extant and proposed access routes in the WFR.**

To the extent possible, traffic (pedestrian, equestrian, cyclist) on the Nā Ala Hele trails is intended to remain separate from traffic (pedestrian, UTV) on the proposed access routes. In the case of agroforestry UTV routes, the systems do not physically intersect and thus present no opportunity for e.g. equestrian recreationalists to negatively interact with a permitted agroforestry contractor or group of community volunteers conducting fruit orchard maintenance. In the case of temporary site preparation access routes, it will be unavoidable for walking crews, potentially with UTV assistance, to periodically cross the Ditch trail or to traverse the Demonstration trail. Strategies to ensure safety and civility during these unavoidable mergers are further discussed below (§3.3.4).

## 3. Management Prescriptions

Assignment of species to compartments is contingent on three factors, (1) suitability of the site soil resource profile, (2) compartment accessibility, and (3) proportional acreage dedicated to the species. The management prescriptions for each FMC therefore include an assessment of each of these factors, which requires soil sampling and analysis, determination of access distances via GIS, and apportionment of acreage to account for extant market share, likely productivity, and community input.

### 3.1. Soil testing

During the planning phase, in which soil nutrient and property tests are unavailable at the field level, assigning field classes becomes a necessary simplification. Prior to implementation, however, a series of soil tests are recommended to identify the most appropriate species or set of species for each field. Certain trees may be more or less appropriate for a given field based on locally heterogeneous soil properties, for example *Mangifera indica* favors well-drained soils whereas *Persea americana* can tolerate a greater degree of poor drainage. Identifying the primary soil characteristics of each field can be achieved by comparing results from several soil analyses.

Sampling should occur at a frequency of at least one sample per agroforestry field for fields less than 5 ac, or two samples per field for larger fields. Timber compartments can occupy larger areas or more extensive elevation gradients; soils should be sampled according to a combination of elevation change (one sample per 300 ft elevation) and compartment size (0.2 samples per acre), using the more conservative option if funding dictates. Soil samples should be collected according to guidelines published by the University of Hawaiʻi (UH) College of Tropical Agriculture and Human Resources (CTAHR), which describe a composite sampling strategy (**Appendix D**) that is adaptable to most analytical procedures.

Soil analyses should include (1) pH and electrical conductivity, (2) base saturation (BSat) and effective cation exchange capacity (eCEC), (3) moisture content and bulk density, (4) mineral content (calcium (Ca), potassium (K), magnesium (Mg), sulfur (S), boron (B), iron (Fe), aluminum (Al)), (5) organic nutrients (N, C, soil organic matter). A wide variety of soil testing options are available, from private analytical companies to public university laboratories. Testing labs at UH CTAHR have the benefit of technicians with more extensive experience in tropical soils and agriculture, though per-sample pricing is less competitive. Other options (e.g. Waters Agricultural Testing Laboratory[4]) offer more competitive per-sample pricing and a wider range of available tests, but their interpretive experience may be comparatively limited.

[4] http://www.watersag.com/frame.htm

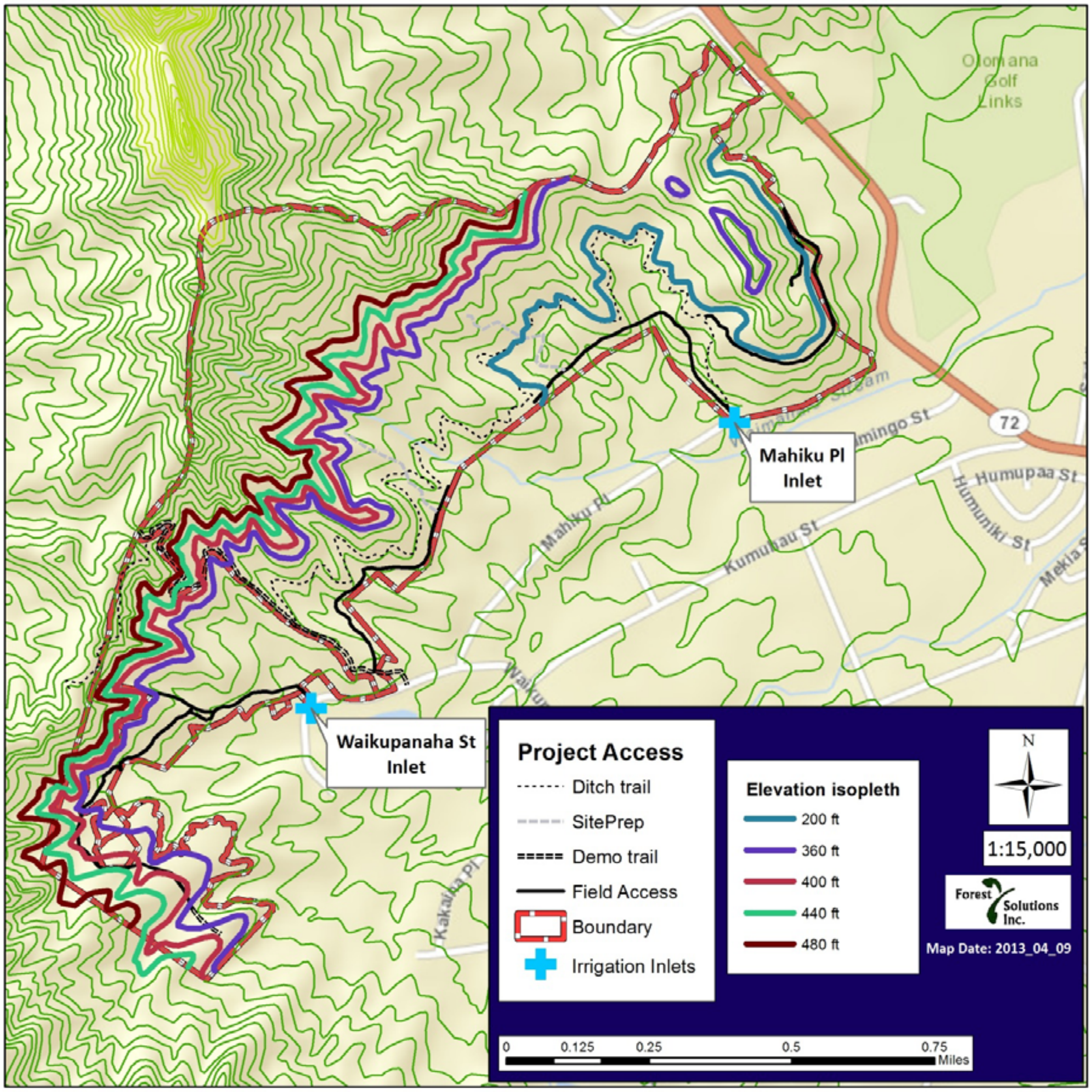
## 3.2. Irrigation

Average annual precipitation in the WFR and the Waimānalo Valley in general is approximately 42 inches (1000 mm), most of which occurs during winter months (§1.2.3). To survive and attain optimum productivity levels, many of the agroforestry crops selected for this FMP either require greater rainfall or less seasonality in its distribution. Consequently, irrigation would be necessary for many crops, in some cases to ensure that the trees survive during early establishment, and in other cases to promote fruit production. Although the Department of Agriculture maintains the Waimānalo irrigation ditch within the boundary of the WFR TMK, this water cannot be accessed until it has reached the Waimānalo Irrigation Reservoir. Water for use within the WFR would need to be acquired from post-reservoir pipelines located on Waikupanaha Street (a 10" pipe) and on Mahiku Place (a 6" pipe) (

**3.2.1**

Figure 3.2.2).

Water pressure from the source pipes would suffice for irrigating compartments at approximately the same elevation (e.g. 40 feet above sea level (asl), likely not more than 60 feet asl), but irrigation above this elevation would not have enough pressure to reliably operate valves and emitters. Possible solutions to inadequate water pressure include an active pump station connected to the electrical grid, or a gravity fed system in which a pump replenishes water stored in tanks at higher elevations. The investment required for these systems can be determined only after the particular management prescriptions for the WFR have been selected. If cropping systems with low water requirements are selected, or low yields can be tolerated for systems that that usually need abundant soil moisture,




**3.2.1**

**Figure 3.2.2. Inlets for irrigation are located where the WFR boundary intersects Waikupanaha Street and Mahiku Place. Potential locations for water storage tanks within the WFR would be selected such that areas below the tank elevation isopleth could be irrigated.**

## 3.3. Objectives by forest management class

### 3.3.1. Watershed

Virtually the entire WFR is currently occupied by invasive tree species, yet soil structural integrity of the steep watershed compartments (Figure 3.3.1) depends on unbroken vegetation cover and intact tree root systems. Management in these areas thus presents a conundrum: improve representation of native Hawaiian species in the watershed while simultaneously maintaining vegetation cover.

**Figure 3.3.1. Topography in watershed compartments (top) contains steep slopes (left) occasionally with severe erosion problems (right). Shallower slopes with no erosion problems are more typical of agroforestry compartments (bottom), which contain trails (left, Ditch Trail) and overgrown areas (right).**

The crux of this problem lies in promoting native species—which tend to be relatively less competitive —while allowing non-native species—typically aggressive competitors —to continue to grow. The problem may be solved by recognizing that soil structure can be maintained to a sufficient degree even as the total number of trees, and therefore the summed competitive environment (CIT neighborhood), decreases . Watershed protection and ecosystem restoration are achieved via a sequential process:

(1) Native Hawaiian species may be introduced (§3.2.1.2) to the system as a replacement for decimated invasive understory trees (§3.2.1.1).

(2) Native species may be promoted by fertilizer application and local weed control (§3.2.1.2)

(3) Overstory trees may be terminated after the native species have occupied enough space to ensure adequate soil stability and erosion control.

### *3.3.1.1. Invasive tree removal and canopy maintenance*

This objective can be achieved by terminating several invasive trees in a restricted area that ensures continuous canopy closure. The exact prescription varies with local canopy structure: where single overstory canopy trees occupy areas many meters to a side, understory vegetation can be killed or removed (§3.3.2.2) terminated across as many as e.g. 100 $m^2$. Typically, the difference between overstory (tallest trees) and understory (subcanopy) is quite pronounced (Figure 3.3.2), and it is a simple matter to selectively terminate the understory trees (Figure 3.3.2).



**Figure 3.3.2. Multi-story forest in the WFR contains areas with dense short-statured juvenile trees (top), as well as more open understory (center). Though there are fewer canopy emergent trees (bottom) per acre, these tree occupy most of the WFR in terms of canopy cover.**

Where the overall vegetation stature is low (i.e. there is only canopy, and no subcanopy), effectively unbroken tree cover (from the perspective of erosion control) can be maintained at disaggregated densities of 100 $ft^2$ (9.3 $m^2$) basal area on 1.0 acres 0.4 ha (Waltert *et al.* 2005). This target basal area allows land managers to identify appropriate residual densities without needing to characterize the full range of extant vegetation conditions from the outset. Implementation could take the form of removing regularly-sized small blocks for planting shade tolerant species or removing somewhat larger blocks to accommodate shade intolerant species—both approaches reduce local basal area density to an equivalent degree.

#### *3.3.1.2. Native species planting and maintenance*

In areas liberated from invasive species (per §3.2.1.1), native Hawaiian tree, shrub, and herbaceous species (Table 3.3.2) should be planted at densities that balance survival with site occupancy. Prescriptions vary by final plant stature. For example, the tree species *Sophora chrysophylla* (māmane) rarely exceeds a final canopy height of 16 ft (5 m) or canopy diameter of 13 ft (4 m), and plantings often suffer from a 60% mortality rate in comparable settings. Consequently, an initial spacing of 13' x 13' that would lead to full site occupancy at 258 trees per acre (tpa) would actually be achieved via a 10' x 10' spacing at 430 tpa, accounting for the likely mortality rate. Species of a smaller final stature, for example the shrub ulei or the herbaceous sedge ahuawa, should be planted at densities consistent with probable mortality and the final spacing objective (Table 3.3.2). Planting prescriptions presented here (Table 3.3.2) are intended as a basic guide to community groups interested in watershed restoration.

Prescriptions and species ultimately used for the project may vary if the work is undertaken by, for example, an NGO that employs alternate established methodology. Given the potential variation in technique, additional prescriptions (fertilizer, irrigation, provenance selection, etc.) are left to be determined by those who implement the project. A broadly applicable fertilizer regime (Table 3.3.1) uses a controlled release formulation to slowly introduce soil nutrients around plantings. This approach is especially suitable to watershed areas because slower release of nutrients minimizes downstream eutrophication and leads to less weed growth. The schedule for implementing prescriptions to restore native species would be analogous to that for establishing timber plantings (§3.3.2, Table 3.3.4).

**Table 3.3.1. Sample fertilizer regime for native Hawaiian species planted in watershed compartments. Fertilizer formulations are typically expressed by percentage elemental nitrogen (N), phosphorus (P), and potassium (K). Per-tree doses of fertilizer product vary from 2 to 4 ounces; corresponding elemental doses are calculated by applying the relevant percentage multiplier.**

| Month | Formula | oz. / tree | N (oz.) | P (oz.) | K (oz.) |
|---|---|---|---|---|---|
| 0 | 15-09-12-μ | 2 | 0.3 | 0.2 | 0.1 |
| 12 | 10-30-10 | 4 | 0.2 | 0.6 | 0.0 |

**Table 3.3.2. Native species appropriate for watershed restoration plantings in WFR. Species are ranked according to their suitability for the site. Suitability was determined by several criteria, including current presence on site, historical range, and known performance trials.**

| Genus | Species | Common | Market | Purpose | Rank* | Origin |
|---|---|---|---|---|---|---|
| *Alphitonia* | *ponderosa* | kauila | --- | Tree | 2 | NAT |
| *Alyxia* | *oliviformis* | maile | Gather | Understory | 2 | NAT |
| *Bidens* | *spp* | koʻokoʻolau | --- | Understory | 2 | NAT |
| *Cordyline* | *fruticosa* | ti | Gather | Understory | 2 | NAT |
| *Cyperus* | *javanicus* | ahuawa | --- | Understory | 2 | NAT |
| *Diospyros* | *hillebrandii* | lama | Timber | Tree | 2 | NAT |
| *Heteropogon* | *contortus* | pili | --- | Understory | 2 | NAT |
| *Microlepia* | *strigosa* | palapalai | --- | Understory | 2 | NAT |
| *Nephrolepis* | *cordifolia* | kupukupu | --- | Understory | 2 | NAT |
| *Osteomeles* | *anthyllidifolia* | ulei | --- | Understory | 2 | NAT |
| *Pandanus* | *tectorius* | hala | --- | Understory | 2 | NAT |
| *Piper* | *methysticum* | awa | Gather | Understory | 2 | NAT |
| *Pipturus* | *albidus* | mamaki | Gather | Tree | 2 | NAT |
| *Plumbago* | *zeylanica* | ʻilieʻe | --- | Understory | 2 | NAT |
| *Rauvolfia* | *sandwicensis* | hao | --- | Understory | 2 | NAT |
| *Sapindus* | *oahuensis* | lonomea | --- | Understory | 2 | NAT |
| *Myoporum* ** | *sandwicense* | naio | --- | Tree | 1 | NAT |
| *Santalum* | *freycinetianum* | iliahi | Timber | Tree | 1 | NAT |
| *Acacia* | *koaia* | koaia | --- | Tree | 0 | NAT |
| Acacia** | *koa* | koa | Timber | Tree | 0 | NAT |
| *Broussonetia* | *papyrifera* | wauke | --- | Tree | 0 | NAT |
| *Dodonea* | *viscosa* | aʻa liʻi | --- | Understory | 0 | NAT |
| *Metrosideros* | *polymorpha* | ʻōhiʻa | Post | Tree | 0 | NAT |
| *Pritchardia* | *martii* | loulu | --- | Tree | 0 | NAT |
| *Sophora* | *chrysophylla* | māmane | --- | Tree | 0 | NAT |
| Erythrina** | *sandwicensis* | wiliwili | --- | Tree | -1 | NAT |

## 3.3.2. Timber

### *3.3.2.1. Erosion mitigation*

All timber stand establishment must occur within the framework of maintaining sufficient tree cover to prevent erosion. **Should mechanical site preparation be chosen over manual site preparation, only a relatively low-impact approach such as a tracked, self-propelled chipper is recommended because other techniques are inconsistent with the goal of maintaining continuous forest cover.** Moreover, the topography is highly heterogeneous throughout even relatively flat compartments; this inconsistent terrain drastically decreases the effective area within which typical heavy machinery (e.g. bulldozer, excavator-mounted chipper) can operate safely and efficiently (Figure 3.3.3). While the current vegetation composition in compartments designated for timber is essentially identical to steeper watershed slopes, the significantly lower risk of erosion (Montgomery 2003) in these areas will enable more effective invasive species removal and site preparation.

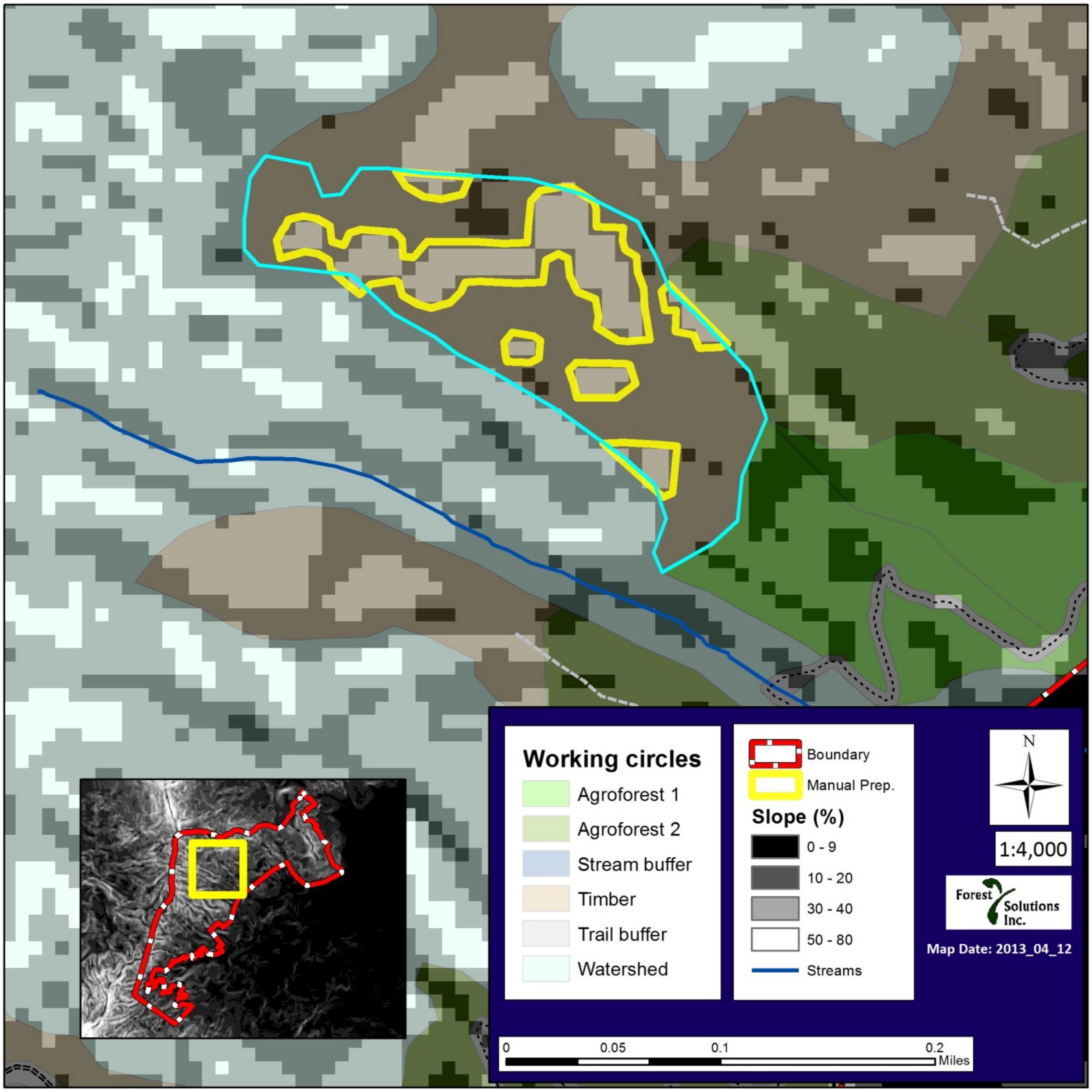



**Figure 3.3.3. In a given compartment (blue outline), areas in which mechanical site preparation would be feasible (beige) are diffused within a matrix of impassable terrain (yellow). Variable terrain in the WFR negates the main advantage of mechanical site preparation, which derives from its superiority in situations where terrain is uniform.**

In steeper timber compartments, the critical requirement for site preparation is controlling the ratio of linear distance to vertical change over which surface water may flow unimpeded by vegetation (primarily root systems). That is, more extensive vegetation cover must be maintained on steeper slopes, while areas may be prepared for planting on flat ground. This prescription follows a concise formula: buffer strips of intact invasive species cover (width 2 m) should temporarily remain at every increment of 4 m elevation change. Exact locations of these buffers (Figure 3.3.4) are determined from a digital elevation map, and would be clearly marked prior to any form of site preparation. Moreover, areas within compartments where slope locally exceeds 20% would be ineligible for canopy openings. Vegetation retention buffers (purple lines, Figure 3.3.4) may consist of 2 m strips of small statured or midstory trees, or individual overstory trees at relatively wide spacing, as long as the buffer includes a continuous root system across the slope. On shallow slopes, the slope-parallel distance between vegetation buffers may permit up to 10 or 15 rows of agroforestry or timber species, with rows spaced 2 m apart (Figure 3.3.4). In contrast, on steep slopes, the vegetation buffers must be closer together, so that only two or three rows may be accommodated (Figure 3.3.4).

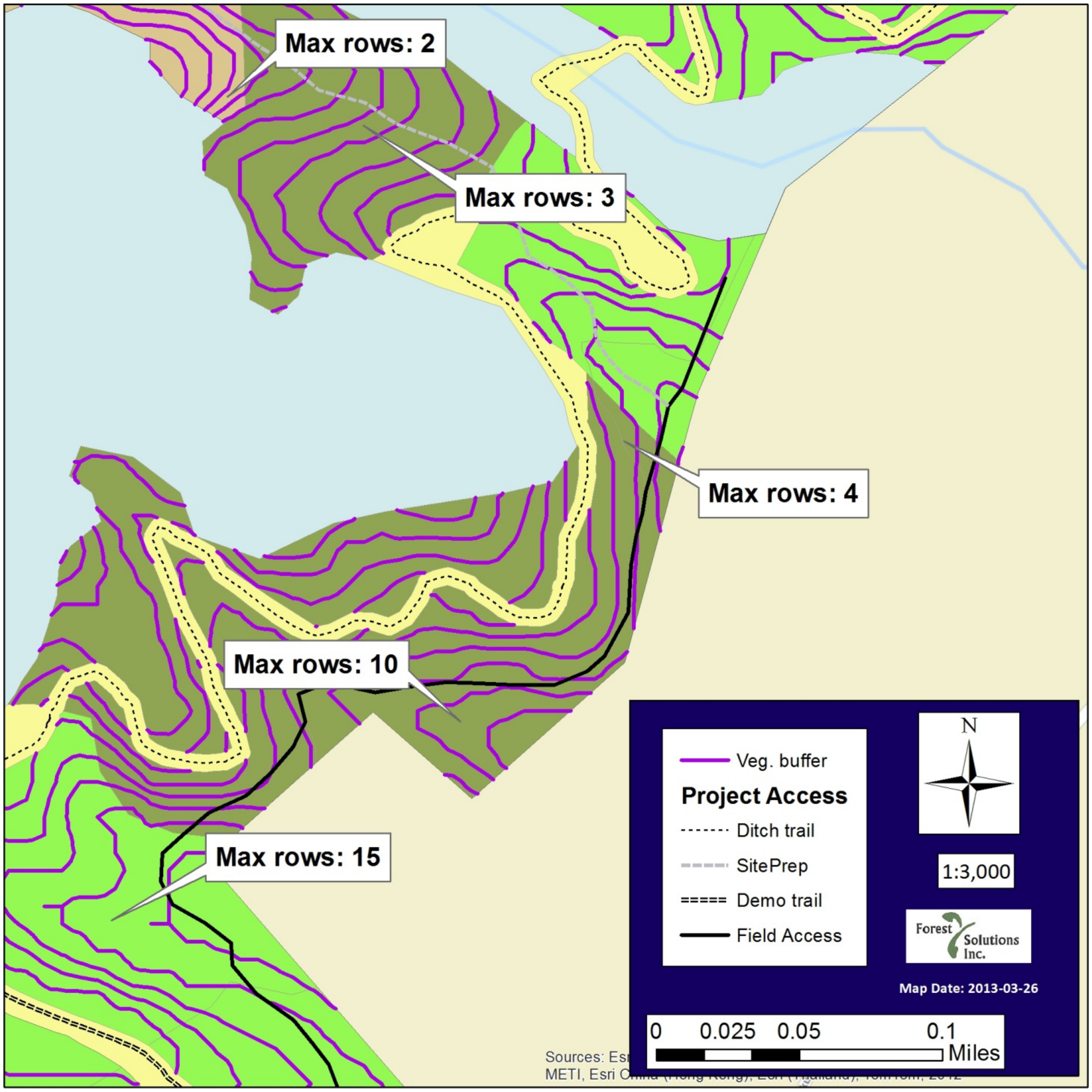



**Figure 3.3.4. Site preparation in timber compartments should occur outside of designated tree buffers. Establishment of timber plantings requires temporary termination of surrounding vegetation, which may allow multiple tree rows (bottom) in flatter areas or may be limited to single rows (top) on steep slopes.**

### *3.3.2.2. Site preparation: manual*

Manual site preparation methods are appropriate for projects whose capital foundations can support site preparation costs between $1,100 and $3,500 per acre, or projects in which the stakeholders have an abundance of time but a lack of capital. Although some of the selected timber species are highly shade and drought tolerant, even these taxa would have limited ability to compete with the existing cover of invasive tree species. Thus, the competitive effects of existing trees must be neutralized before seedlings of high-value or endemic species may be planted. Two pathways may be followed to establish timber trees, with each pathway appropriate for a subset of the suggested species based on shade tolerance.

For the more shade tolerant (ST) species, it would be possible to expedite site preparation using various kill-in-place methods. Broadly, these procedures use a targeted application of herbicide chemicals to terminate the existing overstory. Highly shade tolerant timber species may be planted during the same operation, as long as the selected herbicides are compatible. Those species toward the less shade tolerant end of the spectrum may need to be planted after the overstory has been allowed to decompose (leaf loss, some branch loss, potentially even stem collapse). Kill-in-place can be accomplished using a range of herbicide chemicals, some of which are appropriate for certain species but less effective for others.

The areas where existing trees could be terminated are determined by topography. The steepest slopes in timber compartments may allow only a single row of high-value plantings between retained buffers (Figure 3.3.4). In these areas, invasive overstory and understory species would be treated in a 6 m strip between buffers using the appropriate herbicide agent and application method (Figure 3.3.5). Very large canopy trees are exceptions to the kill-in-place prescription for two reasons. First, the size of these trees may limit the cost effectiveness of herbicides because very large doses may be necessary. Second, terminating such trees in place produces a serious safety hazard from unpredictable collapse of branches and even whole trees. In places where large trees cast deep shade, trees may be felled or planting may skip the area.

**Figure 3.3.5. Systemic herbicides may be applied to target trees by disrupting the bark with a blade (left) or drill bit (center), or by using an oil-based penetrant to deliver chemical to vascular tissues (right).**

For species that show marginal shade tolerance, it would be necessary to physically remove sections of the existing overstory. These limited area clearings are appropriate for more shallow slopes, and conform to the overall management goal of maintaining a continuous forest for the purpose of erosion control. This method of site preparation would also conform to the buffer strips assigned by slope (Figure 3.3.4). Here, existing trees would be manually felled using a chainsaw for larger trees or a machete, hand saw, or similar implement for smaller stems. Fallen trees would be arranged in an organized windrow following slope contour, leaving at least half a meter between windrows for subsequent plantings. The same systemic herbicides applied for kill-in-place are also appropriate for applying to the severed stumps in these limited clearing situations (cut-stump treatment), with herbicides applied using a spray bottle or surface applicator. There is some latitude for a combined approach in a single area, for example physical removal and cut-stump treatment of small stems and frill application to larger trees.

### *3.3.2.3. Site preparation: mechanized*

In contrast to manual site preparation, mechanized site preparation (costing not less than $600 per acre and often substantially more), is appropriate only for projects with sufficient startup capital. The approach to vegetation removal should follow the concerns outlined for manual site preparation, with some important differences. First, mechanized site preparation would be appropriate only for timber and agroforestry compartments; watershed compartments are too steep even for the option recommended here. In appropriate compartments, the general procedure of mechanized site preparation would conform to the vegetation buffer placement cited above (Figure 3.3.4). Actual removal of the existing vegetation should use a Gyro Trac G25 (Figure 3.3.6), which is a 225-bhp hydrostatic drive machine with a rotating cutter head to reduce standing trees into mulch. The machine can chip trees of virtually any diameter, although the time required to chip larger trees is substantially greater than the time required to chip brush. An advantage of the Gyro Trac is its relatively small size, which allows superior maneuverability in rough terrain as well as ground operating pressures typically lower than a human footprint. The machine is transported on a small flatbed trailer (Figure 3.3.6) rather than a lowboy trailer, which can substantially reduce costs for small projects.

**Figure 3.3.6. The Gyro Trac G25 self-propelled brush chipping machine (left) can easily and safely clear brush and trees with minimal impact to soils. The Gyro Trac can be transported on a small flatbed trailer (right), which may make its use on relatively small-scale projects economically feasible.**

To minimize soil disturbance, machine work should not occur during or after heavy rainfall, which is more frequent from November through January. Mechanized clearing would be limited to slopes that do not exceed 30%, which is a safe maximum for tracked machinery. Local slope would need to be determined using a clinometer; in areas where slope locally exceeds 30%, manual clearing using chainsaws is prescribed. Pathways to move machines across tree buffers between clearing zones should be at least 20 m apart. In locations consisting of overstory species prone to sprouting from roots or sheared stems, it will be necessary to apply herbicide (e.g. triclopyr, imazapyr, aminopyralid) to stumps or roots to prevent regrowth; the herbicide application can be concurrent with chipping. A fourth factor to consider is the presence of hazard trees, which are usually *F. moluccana* but may include *A. formosa*. These species, especially *F. moluccana*, readily shed large branches that can cause fatalities. In this aspect, mechanical site preparation shows a clear advantage over manual site preparation in terms of liability and danger to work crews, as the Gyro Trac operator works in a secure cab structure that withstands falling trees.

A final consideration for site preparation should be whether to mechanically prepare the soil for planting or to manually dig holes for seedlings. The decision on this matter should be made after completing a small pilot study to compare seedling performance when grown in holes prepared by a mechanized auger versus comparable seedlings grown in holes created using a shovel or pick. In heavy clay soils, it is possible for soil augers to form a hardpan layer ('clay pot effect') that can lead to wind-throw or limit root growth. With either site preparation method, rows should be located according to spacing recommended in the silvicultural prescriptions for target species (§1.4). Recall that on some steep slopes, buffer strips may allow planting only a single row of trees, whereas many rows can be planted between buffers on flatter areas (Figure 3.3.4).

### *3.3.2.4. Planting*

Species selection (Table 3.3.4), and thus silvicultural requirements, will depend on the level of resources available to implement the plan. An array of options is presented (§4), but each plan would share basic planting procedures. Seedlings would be purchased primarily from the Hawaiʻi State Tree Nursery in Kamuela, or from several private nurseries that supply rare species not offered by the Kamuela nursery. Contracted or volunteer crews would manually plant each seedling, using a planting stick (dibble bar) to perforate the soil for species with small root stock or a trenching shovel for species with larger root stocks. Immediately before planting, seedling should be dipped in a mixture of water, hydrating gel, and fertilizer; additional fertilizer may be applied within the first month of planting to assist the seedling with competing against weeds.

**Table 3.3.3. Contractor(s) conform to this silviculture schedule during the first 30 months to establish timber plantings; thereafter, the minimal silvicultural responsibilities (growth monitoring, IPM) would revert to DLNR DOFAW, with harvesting at a much later date (e.g. year 45).**

| Phase | Activity | Year 0 | | Year 1 | | | | Year 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| Site preparation | Overstory removal | ■ | | | | | | | | | |
| | Soil preparation | | ■ | | | | | | | | |
| Establishment | Planting | | | ■ | | | | | | | |
| | Competition ctrl 1 | | | ■ | | | | | | | |
| | Fertilizer 1 | | | ■ | | | | | | | |
| Silviculture | Competition ctrl 2 | | | | | ■ | | | | | |
| | Fertilizer 2 | | | | | | ■ | | | | |
| | Form control 1 | | | | | | | ■ | | | |
| | Competition ctrl 3 | | | | | | | | ■ | | |
| | Form control 2 | | | | | | | | | | ■ |

**Table 3.3.4. Timber species appropriate for WFR include the native Hawaiian species *Thespesia populnea* (milo), as well as many non-invasive species that produce highly valuable wood.**

| Genus | Species | Common | Weed risk | Market | Purpose | Rank* | Origin |
|---|---|---|---|---|---|---|---|
| *Auraucaria* | *columnaris* | Cook Is. pine | -5 | Expand | Timber | 2 | NON |
| *Calophyllum* | *inophyllum* | kamani | 6 | Expand | Value | 2 | NAT |
| *Cedrela* | *odorata* | trop. cedar | 2 | Expand | Value | 2 | NON |
| *Cupressus* | *leylandii* | Leyland cypress | NA | Expand | Value | 2 | NON |
| *Cupressus* | *lusitanica* | Mexican cypress | NA | Expand | Timber | 2 | NON |
| *Diospyros* | *ebenum* | Ceylon ebony | NA | Global | Value | 2 | NON |
| *Elaeocarpus* | *angustifolius* | blue marble | 4 | Undev. | Timber | 2 | NON |
| *Eucalyptus* | *cloeziana* | QLD messmate | -1 | Undev. | Timber | 2 | NON |
| *Eucalyptus* | *microcorys* | tallowwood | 1 | Undev. | Timber | 2 | NON |
| *Guaiacum* | *sanctum* | lignum vitae | -6 | Global | Value | 2 | NON |
| *Khaya* | *senegalensis* | Afr. mahogany | 0 | Global | Value | 2 | NON |
| *Pterocarpus* | *indicus* | narra | 4 | Expand | Value | 2 | NON |
| *Samanea* | *saman* | monkeypod | 4 | Expand | Value | 2 | NON |
| *Santalum* | *freycinetianum* | iliahi | --- | Expand | Value | 2 | NAT |
| *Senna* | *siamea* | pheasantwood | 4 | Expand | Value | 2 | NON |
| *Sweitenia* | *macrophylla* | Hon. mahogany | -2 | Global | Value | 2 | NON |
| *Syncarpia* | *glomulifera* | turpentine | NA | Undev. | Timber | 2 | NON |
| *Thespesia* | *populnea* | milo | --- | Expand | Value | 2 | NAT |
| *Aquilaria* | *crassna* | agarwood | NA | Global | Value | 1 | NON |
| *Caesalpinia* | *echinata* | pau-brasilia | -3 | Global | Value | 1 | NON |
| *Calycophyllum* | *spruceanum* | pau-mulato | NA | Undev. | Value | 1 | NON |
| *Cordia* | *subcordata* | kou | -3 | Expand | Value | 1 | NON |
| *Eucalyptus* | *torelliana* | cadagi | 4 | Undev. | Value | 1 | NON |
| *Pinus* | *caribea* | Caribbean pine | NA | Global | Timber | 1 | NON |
| *Pinus* | *tecunumanii* | Guatemalan pine | NA | Global | Timber | 1 | NON |
| *Tectona* | *grandis* | teak | -5 | Global | Value | 1 | NON |
| *Acacia* | *koa* | koa | --- | Hawaii | Value | 0 | NAT |
| *Astronium* | *fraxinifolium* | tigerwood | NA | Undev. | Value | 0 | NON |
| *Ochroma* | *pyramidale* | balsa | NA | Global | Timber | 0 | NON |

### *3.3.2.5. Silviculture*

Timber compartments would remain under the administration of DLNR DOFAW (§2.3), with tree establishment to be completed by contract through the RFP process. An important component of the establishment phase is adequate silviculture in the two years after planting. During this critical time, seedlings must be induced to grow quickly and out-compete weed species. Success in this phase disproportionately influences the overall project outcome, since poor establishment will translate to slow growth and low yield. The template silvicultural prescription schedule (Table 3.3.3) is applicable to all tree species selected for this FMC; specific requirements should be applied based on species level prescriptions (§1.4).

#### *3.3.2.6. Harvesting*

**Economic feasibility of the hardwood timber prescription hinges on the ability to eventually harvest trees. Although harvest protocol is not a primary component of the management plan at this stage in its development, one element of the EA, and discussions with the OCCL, must be a clarification about whether low-impact harvesting would be permitted in the reserve. If harvesting would be allowed, then the timber component of this plan should be pursued. On the other hand, an unfavorable assessment of harvesting in the EA or OCCL interactions may constrain future operations to such an extent that it may be prudent to reclassify timber compartments in the Watershed FMC.**

Many of the high-value hardwood species selected for this project require relatively lengthy rotations typically exceeding 25 years. Although it is not possible to predict exactly how harvesting would occur in the future, a selection harvest approach is envisioned for the WFR. All harvesting would conform to the State of Hawai'i Best Management Practices (BMP) manual, or its future derivation (**Appendix E**). Current BMP would mandate harvesting via a selection system in which trees are felled with a chainsaw, removed from the site using a tracked vehicle capable of low ground operating pressures, and transported to mill using a self-loading or assisted-loading truck.

Some limited cultural timber harvesting may occur in the form of removing *F. moluccana* trees for use as practice canoe carving logs. Felling would be accomplished manually using chainsaws; removal of the large log sections would most likely require some mechanized assistance such as a log arch attached to a UTV. This cultural use of non-traditional tree species preserves human and non-human resources by allowing Hawaiian cultural knowledge (traditional canoe manufacture) to be transmitted across generations while at the same time preserving increasingly rare canoe-log-size *Acacia koa* trees.

### 3.3.3. Agroforestry: Intensive and Moderate

#### *3.3.3.1. Site preparation*

Despite shallower slopes overall in agroforestry compartments, the role for mechanized site preparation would be limited by an assortment of factors: locally steep sections, proximity to blue line streams, issues with access, and the inherent inefficiency of mechanization for small acreages. Several relatively flat compartments with good accessibility could be eligible for mechanical site preparation, assuming sufficient net present value of the selected agroforestry system (§5.1.4). In these special cases where suitable terrain and financial viability support mechanized site preparation, appropriate machinery could include rubber-tracked excavators such as the Bobcat E45 (41.8 hp, 10,077 lbs) or the Case CX31B (28.4 hp, 6,679 lbs) equipped with thumbs to facilitate moving slash into organized windrows. Felling would be accomplished using chainsaws, as specialty mechanized options are price-limited for equipment and projects of this size.

Most, if not all, site preparation for agroforestry would be manual, with procedures identical to timber site preparation (§3.3.2.2). For the cut-stump applications necessary to prepare agroforestry sites, herbicide application would follow the same prescription as for timber (Figure 3.3.5). Agroforestry site preparation diverges from timber protocol primarily in terms of geometry and shade tolerance, where the windrow regime may be appropriate for some applications (e.g. understory replacement such as cacao or coffee) but inappropriate for others (e.g. establishing single isolated fruit trees or mosaics of multiple canopy-stature fruit trees).

**Table 3.3.5.** A standard silvicultural schedule is advanced for all agroforestry prescriptions**. Particular adjustments to the schedule include different spacing, fertilizer formulations, herbicides, and minor adjustments to timing.**

| Phase | Activity | Year 0 | | Year 1 | | | | Year 2 | | | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q2 | Q4 | Q2 | Q4 | Q2 | Q4 |
| Site preparation | Overstory removal | ■ | | | | | | | | | | | | | | | |
| | Soil preparation | | ■ | | | | | | | | | | | | | | |
| | Irrigation install. | | ■ | | | | | | | | | | | | | | |
| Establishment | Planting | | | ■ | | | | | | | | | | | | | |
| | Competition ctrl | | | ■ | | | | | | | | | | | | | |
| | Fertilizer | | | ■ | | | | | | | | | | | | | |
| Silviculture | Competition ctrl | | | | | ■ | | | | | | ■ | | ■ | | ■ | |
| | Fertilizer | | | | | | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Form control | | | | | | | | | | ■ | | | | | | ■ |

Particular prescriptions for site preparation geometry are presented on a species basis (§1.4), but may be broadly classified as either windrow regimes for shade-tolerant or understory species versus single tree clearings for shade intolerant species. Removal of existing stems may follow the windrow regime for establishing shade tolerant agroforestry species or a small clearing regime to establish shade intolerant species. Slash from cut trees may be arranged in a linear windrow or dispersed evenly within single tree clearings to speed decomposition.

Additional minor regime adjustments may be appropriate for some crops, particularly when mechanical subsoil ripping could be useful. For example, access to distantly-spaced (20' x 20') locations for a low intensity avocado planting would not justify subsoil ripping. In contrast, a high-intensity cacao plantation with a *Gliricidia* overstory would benefit from subsoil ripping to improve ease of planting. Due to the diversity of silvicultural requirements for agroforestry crops or multi-crop systems, particular site preparation prescriptions are available in species-level silvicultural regimes (§1.4) and financial model case studies (§5).

### *3.3.3.2. Planting*

As with agroforestry site preparation, planting prescriptions differ substantially by species (Table 3.3.6) and project intensity (§4). Whereas timber species may be planted as plug stock or other forms with relatively small root systems, most fruit trees require larger root systems at planting. For example, jackfruit and avocado perform best when sapling root systems have fully developed in a 2-gallon pot, while cacao seedlings can thrive when grown in 10" band pots. Substantially different planting techniques are necessary for this variety of pot sizes, ranging from manually perforating mechanically ripped lines with a trenching shovel (e.g. for a cacao-*Gliricidia* system), to mechanically digging individual sites with a mini excavator (e.g. for a monotypic early production ulu plantation). Several case studies (§5) and species-level silvicultural regimes (§1.4) provide further detail regarding planting techniques.

**Table 3.3.6. Agroforestry species include both canopy trees and smaller-statured species appropriate for planting within a matrix of larger trees.**

| Genus | Species | Common | Weed risk | Market | Purpose | Rank* | Origin |
|---|---|---|---|---|---|---|---|
| *Anacardium* | *occidentale* | cashew / apple | 0 | Comm. | Nut | 2 | NON |
| *Annona* | *cherimola* | cherimoya | -4 | Expand | Fruit | 2 | NON |
| *Annona* | *muricata* | soursop | -3 | Expand | Fruit | 2 | NON |
| *Annona* | *reticulata* | custard apple | NA | Expand | Fruit | 2 | NON |
| *Arachis* | *hypogaea* | peanut | NA | Comm. | Groundcover | 2 | NON |
| *Arachis* | *pintoi* | golden glory | -1 | NA | Groundcover | 2 | NON |
| *Artocarpus* | *altilis* | ulu | -12 | Comm. | Fruit | 2 | NON |
| *Artocarpus* | *heterophyllus* | jackfruit | 1 | Comm. | Fruit | 2 | NON |
| *Averrhoa* | *carambola* | starfruit | -1 | Comm. | Fruit | 2 | NON |
| *Cinnamomum* | *verum* | cinnamon | 10 | Comm. | Bark | 2 | NON |
| *Coffea* | *arabica* | coffee | 2 | Comm. | Fruit | 2 | NON |
| *Garcinia* | *mangostana* | mangosteen | NA | Expand | Fruit | 2 | NON |
| *Gliricidia* | *sepium* | madre cacao | -3 | NA | Overstory | 2 | NON |
| *Hylocereus* | *spp* | dragon fruit | NA | Expand | Fruit | 2 | NON |
| *Inga* | *edulis* | icecream bean | 2 | Expand | Overstory | 2 | NON |
| *Litchi* | *chinensis* | lychee | -6 | Comm. | Fruit | 2 | NON |
| *Nephelium* | *lappaceum* | rambutan | NA | Comm. | Fruit | 2 | NON |
| *Persea* | *americana* | avocado | 3 | Comm. | Fruit | 2 | NON |
| *Pouteria* | *sapota* | mamey sapote | NA | Expand | Fruit | 2 | NON |
| *Rollinea* | *deliciosa* | Amzn. cust. apple | NA | Expand | Fruit | 2 | NON |
| *Theobroma* | *cacao* | cocoa | -5 | Expand | Fruit | 2 | NON |
| *Trifolium* | *spp* | clover | -1 | NA | Groundcover | 2 | NON |
| *Annona* | *squamosa* | sugar apple | 6 | Expand | Fruit | 1 | NON |
| *Areca* | *catcheu* | betel palm | -4 | Expand | Nut | 1 | NON |
| *Artocarpus* | *odoratissimus* | marang | -3 | Undev. | Fruit | 1 | NON |
| *Bouea* | *macrophylla* | maprang | NA | Undev. | Fruit | 1 | NON |
| *Bunchosia* | *argentea* | peanutbutter fruit | -3 | Expand | Fruit | 1 | NON |
| *Cocos* | *nucifera* | coconut, niu | -4 | Comm. | Nut | 1 | NON |
| *Euterpe* | *oleracea* | acai palm | 5 | Comm. | Nut | 1 | NON |
| *Mangifera* | *casturi* | kasturi | 1 | Undev. | Fruit | 1 | NON |
| *Moringa* | *oleifera* | horseradish tree | 1 | Comm. | Overstory | 1 | NON |
| *Myrciaria* | *cauliflora* | jaboticaba | -2 | Undev. | Fruit | 1 | NON |
| *Myricaria* | *vexator* | blue grape tree | -2 | Undev. | Fruit | 1 | NON |
| *Psidium* | *guajava* | apple guava | 21 | Comm. | Fruit | 1 | NON |
| *Bactris* | *gasipaes* | peach palm | NA | Undev. | Nut | 0 | NON |
| *Macadamia* | *integrifolia* | macadamia nut | -1 | Comm. | Nut | 0 | NON |
| *Manilkara* | *zapota* | sapodilla | NA | Expand | Fruit | 0 | NON |
| *Pouteria* | *viridis* | green sapote | NA | Expand | Fruit | 0 | NON |
| *Salacca* | *zalacca* | snake fruit, salak | NA | Undev. | Nut | 0 | NON |
| *Citrus* | *spp* | citrus | 0 | Comm. | Fruit | -1 | NON |
| *Diospyros* | *digyna* | black sapote | NA | Expand | Fruit | -1 | NON |
| *Manfigera* | *indica* | mango | 1 | Comm. | Fruit | -1 | NON |

* Ranking: 2: Excellent | 1: Reasonable | 0: Possible or Unknown | -1: Drawbacks

A further component of agroforestry is the dynamic between overstory and understory species, including biotic interactions mediated by tree spacing (Phillips 1969, Crane 1989). Some understory species (e.g. *T. cacao*) can tolerate fairly deep shade, and may therefore be planted under overstory species with dense canopy architecture (e.g. *I. edulis*, *A. heterophyllus*). In contrast, other understory species (e.g. *C. arabica*), though they may be able to tolerate deep shade, perform better in terms of fruit production at intermediate shade levels that can be cast by overstory species with a relatively sparse canopy architecture (e.g. *G. sepium*, *A. koa*). Although advantages of intercropping with multiple species include an enhanced nutrient availability, the rapid nutrient cycling rates in tropical soils necessitate additional fertilizer (Table 3.3.7) to achieve economically viable yields (Li *et al.* 1999).

**Table 3.3.7. Sample fertilizer regime for agroforestry systems. Fertilizer formulations are typically expressed by percentage elemental nitrogen (N), phosphorus (P), and potassium (K). Per-tree doses of fertilizer product vary extensively as a function of age, ranging from 5 to 280 ounces; corresponding elemental doses are calculated by applying the relevant percentage multiplier.**

| Month | | Overstory | | | | Understory | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Formula | oz. / tree | N (oz.) | P (oz.) | K (oz.) | oz. / tree | N (oz.) | P (oz.) | K (oz.) |
| 0 | 10-30-10 | 5 | 0.5 | 1.5 | 0.5 | 2 | 0.2 | 0.5 | 0.2 |
| 3 | 11-52-00 | 5 | 0.5 | 2.4 | 0.0 | 1 | 0.2 | 0.7 | 0.0 |
| 6 | 10-30-10 | 5 | 0.5 | 1.5 | 0.5 | 2 | 0.2 | 0.5 | 0.2 |
| 9 | 11-52-00 | 5 | 0.5 | 2.4 | 0.0 | 1 | 0.2 | 0.7 | 0.0 |
| 12 | 11-52-00 | 9 | 1.0 | 4.7 | 0.0 | 3 | 0.3 | 1.4 | 0.0 |
| 18 | 00-45-00 | 10 | 0.0 | 4.6 | 0.0 | 5 | 0.0 | 2.3 | 0.0 |
| 24 | 11-52-00 | 36 | 4.0 | 18.9 | 0.0 | 18 | 2.0 | 9.5 | 0.0 |
| Years 3-4 | 10-30-10 | 80 | 8.0 | 24.0 | 8.0 | 40 | 4.0 | 12.0 | 4.0 |
| Years 5-10 | 10-30-10 | 120 | 12.0 | 36.0 | 12.0 | 60 | 6.0 | 18.0 | 6.0 |
| Years 10+ | 10-30-10-µ | 280 | 28.0 | 84.0 | 28.0 | 60 | 6.0 | 18.0 | 16.8 |

### *3.3.3.3. Maintenance, weed control, and pest control*

An integrated pest management (IPM) framework (Flint *et al.* 2003) is recommended for the agroforestry FMC. The IPM approach, which is useful for both weed and insect pests, focuses on (1) monitoring potential pest agents, (2) identifying threshold densities or populations at which pests cause unacceptable economic damage, and (3) identifying and applying the most effective control agent. To control weeds in IPM, the first objective would be to determine whether a given plant is in fact a competitor for the crop in question. For example, the crop (e.g. cacao) may grow with a tap root and relatively deep rooting system, in which case potential weed species with shallow roots or much smaller overall size may not be competitors. Alternately, in the early phases of development when crop seedlings are very small, any non-crop species may be considered a weed because competitive effects are magnified by size disparity. To control insect pests in IPM, the first step is to identify potential pest species. This requires a monitoring program that can take on varying degrees of sophistication.

If observation or research classifies a plant as a weed species, the second phase of IPM is to determine what density or population level of that plant actually constitutes a threat to economic viability of the crop in question . In the context of native species restoration, economic viability may be replaced by some assessment of ecosystem services or a valuation of biodiversity . Some weed species may need control only at relatively high population densities. For example, the species (basket grass) is widespread in the WFR, but does not aggressively compete with trees and can therefore be tolerated at high densities. In contrast, weed species such as (Australian tree fern) or *Miconia calvescens* have immense potential to escape control, and cannot be tolerated even at low densities regardless of the limited competitive capability shown by individual plants. A similar analysis is applied to insect pests, establishing threshold levels at which a species begins to cause unacceptable damage.

The final phase of IPM involves intervention with appropriate control methods. For weeds, the most effective control may not always be herbicide application. Some weeds may be manually removed (for example, the first detected individual of a particularly threatening species), or weeds may be mechanically killed (mowing, cultivation). Mowing is particularly useful when groundcover vegetation serves to stabilize soil on steep slopes, but would compete with crop plants if allowed to grow to full size. Weed species may be prevented from growing in the first place using agricultural plastics or conventional mulching. Herbicides may have an important role in IPM, but optimizing their use is always the objective. For example, rather than treating a fully-grown weed with e.g. relatively large volumes of glyphosate, it may be possible to apply minimal volumes of pre-emergent herbicides that would prevent the weed seeds from sprouting. Herbicide use is unavoidable for established weeds like tree cover in the WFR, but collateral damage can be nearly eliminated by using appropriate chemicals. For example, although triclopyr (trade names Garlon 4, Garlon 3A, Remedy) is a commonly used chemical for cut-stump applications, its toxicity to aquatic life and low vapor pressure are hazardous. The herbicide aminopyralid (trade name Milestone), on the other hand, shows low aquatic toxicity, no volatility, and may be used at much lower volumes to achieve the same or better outcomes.

To control insect pests in the context of IPM, numerous strategies may be brought into play, including manual collection, pheromone baited traps, sticky traps, organic or botanical deterrents (azadirachtin derivatives, companion plants containing nicotine sulfate) or insecticides (pyrethrin, *Bacillus thuringensis* toxin). Conventional chemical pesticides may also be appropriate, including formulas that cause contact mortality as well as systemic chemicals.  Overall, IPM is an active framework that enables growers to optimize weed and pest control strategies for particular sites, crop species, and available budgets.

#### *3.3.3.4. Cultural plantings*

Traditional Hawaiian cultural plants were often gathered in the forest rather than intensively cultivated . Because these plants, such as *Genspp* (maile), *Genspp* (ti), or *Piper methysticum* (awa), occupy forest niches, they are ideally suited for the agroforestry model. Procedurally, establishing these species does not differ from growing more conventional understory crops such as cacao or coffee: a compatible overstory tree species is planted either prior to or in conjunction with the main crop species. Although native tree species (e.g. ohia, mamane, milo) would be compatible, non-native speices (e.g. inga, moringa, gliricidia) would also be appropriate.

#### *3.3.3.5. Detail: cacao*

Cacao cultivation in Hawaiʻi is accelerating, with locally specific resources[5] available from the Department of Agriculture (DoA) and the University of Hawaiʻi College of Tropical Agriculture and Human Resources (CTAHR). These local resources are augmented by several internationally proven methods that, though not yet widely adopted in Hawaii, are nonetheless appropriate for the WFR. Rather than an extensive review of the literature, several points will be discussed that are particularly relevant to cultivation of Cacao in the Waimānalo Valley.

The species *T. cacao* is fundamentally adapted to tropical rainforest understory conditions: high soil moisture (up to 6000 mm annual rainfall can be tolerated) and atmospheric humidity, limited wind, and warm temperatures. In the Waimānalo Valley, the only compatible condition that predominates is warm

[5] http://www.ctahr.hawaii.edu/oc/freepubs/pdf/AB-17.pdf

temperatures. Annual rainfall of approximately 1000 mm is below the optimal threshold for cacao, and WFR atmospheric conditions are less humid and with higher wind speeds. Growing cacao successfully in the WFR will therefore have two basic requirements, (1) establishment of windbreaks and (2) irrigation. Windbreak plantings are inexpensive and effective, and may feature either timber species (e.g. *C. lusitanica*) or e.g. brushbox (*Lophostemon confertus*) or *Podocarpus spp*. Irrigation would be necessary during the relatively dry months of approximately March through October. Required irrigation volumes would vary by year, but likely seven gallons per tree per week for approximately 35 weeks each year would suffice. One acre of standard density cacao plantation (§4.2.4) including 1000 cacao trees with 70 overstory trees would therefore require 245,000 gallons of irrigation water annually.

Cacao production is thoroughly compatible with the broader mission of maintaining the watershed protection effects afforded by closed canopy forests. Because *T. cacao* occupies understory positions in its original habitat, introducing the species to new systems does not require land clearing that would disrupt the ecosystem service of watershed protection. In some areas, existing overstory could be substituted for prescribed species. For example, the extant *F. moluccana* could potentially be substituted for the shade species *Inga edulis*, and may even be advantageous since no establishment effort would be required.

It is expected that a suite of pests will be problematic to some degree. In particular, cacao is vulnerable to numerous fungal pathogens (e.g. *Phytophthora palmivora*) and several insect pests (primarily rose beetle, *Adoredus sinicus*). Standard practice for managing fungal pathogens includes application of fungicidal agents, typically copper sulfate. To control insect pests, principles of integrated pest management (IPM) would be useful. Establishing cacao plantations within an existing overstory reduces the signature of cacao; for those insect pests that do detect the cacao trees, some may be deterred by the presence of e.g. neem (*Azadirachta indica*) trees, while others, likely the rose beetle, would need to be controlled by application of various pesticide agents, including neem oils, neonicotinoid insecticides, or other agents.

### *3.3.3.6. Detail: coffee*

Coffee cultivation in Hawai'i has a long tradition and has been optimized for many of the Islands' ecoregions[6]. The WFR conforms to almost every recommended parameter for coffee land, with the exception of rainfall; for optimum coffee production, rainfall should exceed 59 inches (recall the WFR annual average of 42 inches), but irrigation could correct this. Although some Hawaiian coffee producers maintain shaded plantations, the majority of Hawaiian coffee is open-grown or nominally shaded. If coffee production was to be adapted for the WFR agroforestry project, cost and productivity estimates developed for the open-grown plantation model would need minor revision. In particular, CTAHR recommends a standard spacing of 5' x 10' for open plantations (total density 871 tpa), but this would likely need to be changed to a more evenly distributed 7' x 7' at a comparable density (889 tpa) to accommodate a uniform distribution of overstory trees and therefore retain watershed protection.

Many of the coffee growing areas in Hawai'i suffer from effects of the black twig borer (*Xylosandrus campactus*), which can also infest cacao, but effective silvicultural techniques (preemptive pruning (Alcorn *et al.* 2006; Krisnawati et al 2010)) and chemical control methods are well established (typically a neonicotinoid such as imidacloprid). Species selection may assist with insect control to a degree: *Coffea arabica* is a preferred host, while is *Coffea robusta* is less susceptible. Unfortunately, *C. arabica* beans are much higher value, while *C. robusta* is used primarily in instant coffee formulations, which is not the market pattern for Hawaiian coffee.

[6] http://www.ctahr.hawaii.edu/oc/freepubs/pdf/coffee08.pdf

Whereas cacao is a rapidly expanding crop in Hawaii, coffee is firmly established, so planting a new coffee orchard promises relatively low return for investment, particularly in areas such as the Waimānalo Valley where predominant ecological conditions will not support production of the highest quality coffee. Aside from the market concerns, however, comparable ecological requirements for cacao and coffee suggest that an admixture plantation could be viable, at least from an ecological and silvicultural perspective.

#### *3.3.3.7. Detail: Fusarium-resistant Acacia koa*

**Section text generously furnished by Niklos Dudley, Director, Hawai'i Agriculture Research Center, 2013**

In Hawai'i, koa (*Acacia koa* Gray) is an endemic timber species of substantial cultural, economic, and ecologic importance. Koa wilt disease, caused by the fungus *Fusarium oxysporum* f. sp. *koae*, causes mortality of koa in native forests and is a major impediment to reforestation with this species. The Hawai'i Agriculture Research Center (HARC) with support from the USDA Forest Service, USDA NRCS and the State of Hawai'i DLNR-DOFAW has an active program to develop wilt resistant koa seed using naturally occurring genetic variation. HARC is able to identify koa seed sources (families) that have an increased frequency of wilt resistance in greenhouse inoculation trials. Families with increased frequencies of resistance are candidates for field trials and seedling seed orchards to produce disease resistant seed.

Two seedling trials were established to evaluate resistance in the field. The Hawai'i Island trial incorporates twelve high-surviving families selected from neighboring populations on the southern flank of Mauna Loa. The O'ahu trial incorporates 34 high-surviving families originating from various ecoregions in the Ko'olau Mountain Range on O'ahu. Additional field sites are scheduled for installation by HARC and DOFAW staff on Maui and Kauai. The field trials will produce disease resistant, ecoregion-specific koa seed available for use by the public. Continued screening of additional koa families for pathogen resistance, retesting families, and developing additional seed orchards in other Hawaii locations are planned.

HARC is currently developing novel agroforestry systems to grow wilt resistant koa with specialty coffee and cacao varities in the understory. Agroforestry has played an important role in the Pacific Islands for thousands of years, but has been in severe decline over the past several centuries. Through the successful demonstration of koa based systems, HARC hopes to convince other land owners the benefits of sustainable agroforestry. HARC is currently working primarily with coffee and cacao as understory species, but there is likely an opportunity for a variety of high value understory crops.

### 3.3.4. Access

Project success depends on a variety of elements, but access is one of the most critical components of the forest management plan. There are three types of access that must be balanced, including recreational access on existing trails, long-term access to agroforestry fields, and temporary access to timber compartments during the site preparation and establishment phases.

#### *3.3.4.1. DLNR Nā Ala Hele trails*

The Demonstration and Ditch trails (Figure 3.3.7) administered by DLNR Nā Ala Hele are extremely important to several stakeholder groups. These trails are the only publicly accessible equestrian routes on all of O'ahu, which has led many equestrian enthusiasts to relocate in and around the Waimānalo Valley. Horse boarding is an established industry in the area, and trail access is the main priority for these operations as well as for their client base. Threats—real or perceived—to equestrian trail access have the potential to derail implementation of the entire agroforestry plan. As such, this management plan has provisions to ensure continued open public access to both Nā Ala Hele trails.

Other legitimate user groups include cyclists and pedestrians, with substantial illegitimate trail use by off-road motorcyclists. Of these groups, the pedestrian contingent presents low risk and limited potential objection to agroforestry activities. Cyclists, in contrast, may raise some objection to agroforestry operations in certain areas because some of the users have cut a network of unauthorized trails throughout the WFR. Legally, these trails have no legitimacy[7] and are not maintained by DLNR Nā Ala Hele; in practice, there is the potential for backlash from the cycling community should access to these trails be restricted. These issues are not insurmountable, but will likely require diligent and respectful public education regarding the purpose of the forest reserve system and the importance of using authorized trails. At the same time, it may be possible to offer a compromise, e.g. by legitimizing favorite cycling trails while closing others in areas that are deemed most suitable for more sensitive agroforestry activities.

Addressing unauthorized motorcycle riding is in the best interest of all legitimate stakeholders. Equestrian users are endangered by motorcycles because horses terrified by the noise or sudden appearance of a motorcycle may throw their riders. Pedestrians and cyclists may be harmed in collisions with motorcycles. Agroforestry practitioners may experience crop damage in early phases or increased risk of theft when crops are mature. Thus, it is in the best interest of all legitimate stakeholders to encourage motorcycling elsewhere.

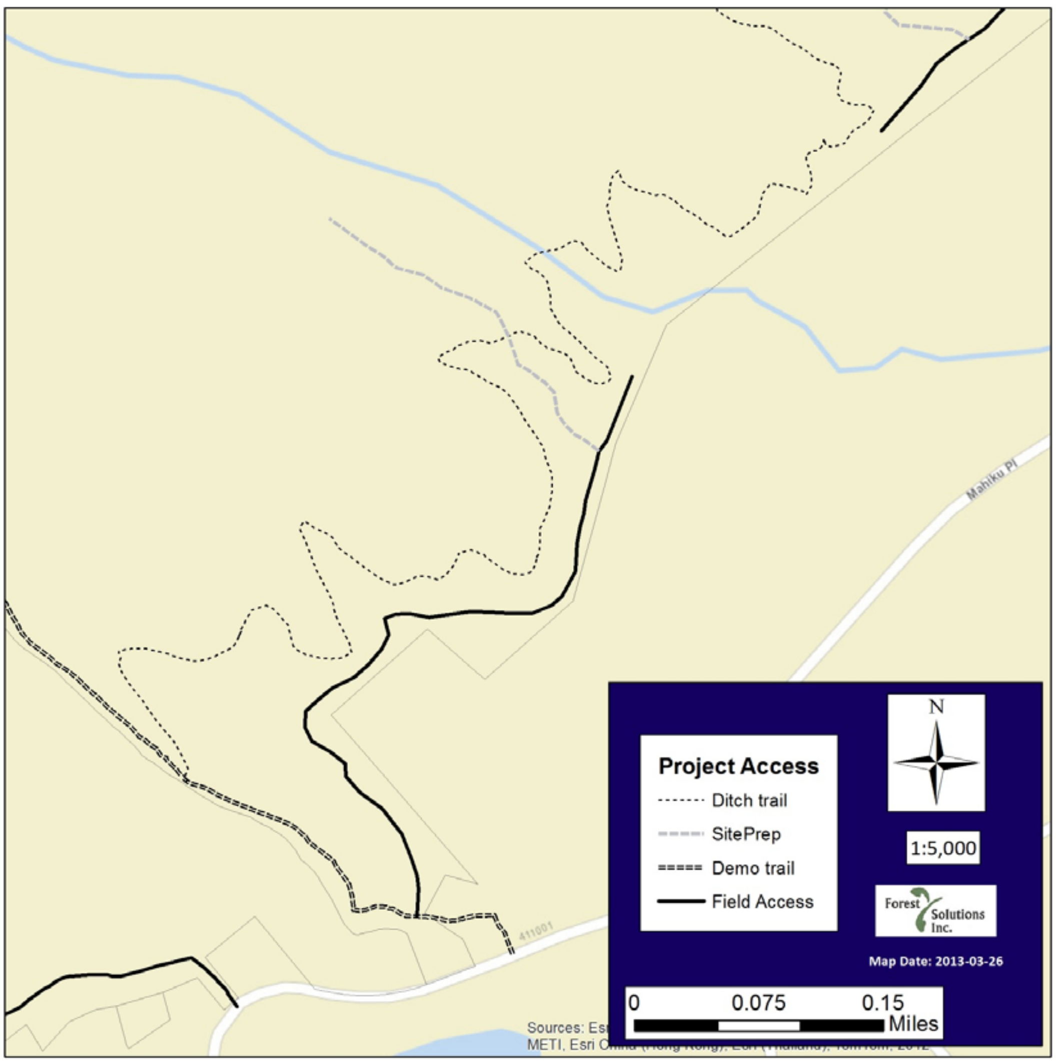



**Figure 3.3.7. Extant Nā Ala Hele trails will remain accessible to the public, and are not to be used for timber or agroforestry purposes. Site preparation paths (grey dash line) would serve as silvicultural access routes for the first two years, and potentially as harvest access many decades hence. Mid-rotation access to timber compartments (e.g. growth and survival research) would be limited to foot traffic via the Ditch and Demonstration trails. Agroforestry fields would be accessed via a separate system (black solid line).**

[7] Pers. Comm., 20130319, Aaron Lowe, DLNR Nā Ala Hele.

### *3.3.4.2. Field access*

To ensure the viability of the various agroforestry projects proposed in this plan, a basic level of accessibility must be established. Compartments designated as agroforestry fields are at present accessible only via the Nā Ala Hele system, either the Ditch or Demonstration trail; dual use of these trails by recreationalists and agroforestry practitioners is inadvisable (§3.3.4.1). All proposed agroforestry access routes (Figure 3.3.7) would be constructed to specifications supporting UTV traffic, and using techniques approved in the Road Construction Standards (**Appendix E**). The decision to limit traffic to UTV's operated by agroforestry contractors or community groups is based on the fact that these vehicles exert lower physical impact on road infrastructure than do bicycles, and cause substantially less structural damage than horses, particular when soils are wet . Both of these latter trail uses are permitted in the WFR on relatively undeveloped Nā Ala Hele trails, so lower-impact UTV traffic on improved access routes will not lead to troublesome erosion. Finally, all proposed agroforestry access routes are located in areas currently zoned for agriculture. Should the EA limit activities permitted in the Conservation District to e.g. removing invasive species, planting productive species, and harvesting non-timber crops, the agroforestry component of this FMP would be allowed to proceed.

### *3.3.4.3. Site preparation access*

Long-term accessibility is not required for the timber compartments, with the majority of activity completed within 24 months of initiation. As a consequence, access routes for the timber compartments would be temporary and limited to vegetation removal on foot or UTV paths used during the site preparation phase (Figure 3.3.7). To the extent possible, intersections with Nā Ala Hele trails will be minimized to two locations, and these temporary intersections would require adequate signage both on site preparation access paths as well as on the trails at least two weeks in advance of any activity. Operators of UTV planting crew support vehicles would be encouraged to limit use of the intersections by bringing a UTV through the intersection accompanied by two assistants stationed on either side of the trail.

### *3.3.4.4. Harvesting*

To reduce entry intervals to the lowest possible frequency, species-site matching (§4) seeks to co-locate species with compatible rotation schedules. For example, aggregates of compartments planted with species that have a 50-year rotation would be situated adjacent compartments containing species that have a 25-year rotation. Thus, during the second harvest entry for the latter species, the harvest contractor could easily access compartments of the former via temporary access built through the logged areas.

# 4. Cost assessment

Constructing comprehensive financial models for every agroforestry species combination is both redundant and unnecessary. A more useful approach is to generate a financial model template (§4.1) that may be used to assess costs for any level of complexity and for any scale, from single species plantings to multi-layered, intermixed plantings (§4.2). Productive agroforestry systems may comprise many individual species, and the number of potential species combinations can be significant (Elevitch and Wilkinson, 2000). For example, if the total number of available species in a prescription is 30, it is a simple matter to identify 75 distinct configurations[8] when limiting the number of planted species to 10. Rather than modeling all of these possibilities, the necessary set of financial models must be capable of calculating costs for any combination via the same algorithm. This requires a single model that can be configured to represent any species assemblage managers may wish to test.

## 4.1. Core financial model

**PLEASE NOTE that the financial models included in this proposal are forest management tools to assist in forecasting estimated project performance. The financial models and their included projections are reasonable assumptions of project performance based upon prior experience but they are not, and should not be considered as, a guarantee of a particular project's outcome by Forest Solutions. Forest Solutions is not a financial advisor and the financial models and their projections we provide should not be used to make financial or investment decisions. Such decisions should only be made with the advice of, and based upon the recommendations of, your financial advisors.**

### 4.1.1. Model input

#### *4.1.1.1. Global parameters*

The foundation of cost assessment for each land use is a financial model that accepts as input an array of cost, scheduling, infrastructure, geometry, and scale variables. The manager selects a suite of species (Table 4.1.1), which may include up to three overstory species, three understory species, one windbreak species, and one groundcover species—more complex models may be approximated by using average parameter values of comparable species. A second set of global variables encodes labor costs, management costs, project acreage, whether irrigation or fencing will be necessary, and a tax exclusive discount rate (Table 4.1.2).

**Table 4.1.1. Template for species selection input for core financial model.**

| Functional group | Common | Species | 1st production | Irrigation | Item explanation |
|---|---|---|---|---|---|
| Overstory 1 | Jackfruit | Arthet | 8.5 | Yes | Enter 1st overstory species; irrigation (Yes/No) |
| Overstory 2 | Inga | Ingedu | 5 | No | Enter 2nd overstory species; irrigation (Yes/No) |
| Overstory 3 | --- | --- | --- | --- | Enter 3rd overstory species; irrigation (Yes/No) |
| Understory 1 | Cacao | Thecac | 5 | Yes | Enter 1st understory species; irrigation (Yes/No) |
| Understory 2 | --- | --- | --- | --- | Enter 2nd understory species; irrigation (Yes/No) |
| Understory 3 | --- | --- | --- | --- | Enter 3rd understory species; irrigation (Yes/No) |
| Windbreak 1 | --- | --- | --- | --- | Enter windbreak species |
| Groundcover 1 | Clover | Trirep | --- | No | Enter groundcover species |

[8] The figure of 75 combinations results from four understory species growing with four overstory species, one groundcover, and one windbreak species. Restricting the available species to a total of 30, with five understory, 21 overstory, two windbreak, and two groundcover, the calculation takes the form of ${}_5C_4 * {}_{21}C_4 * {}_2C_1 * {}_2C_1$, which has a value of 75. Successful configurations may be a smaller subset of potential configurations, with limitations imposed by shade tolerance, soil nutrient requirements, productive life-spans, irrigation requirements, etc.

**Table 4.1.2. Template labor cost input and other global variables.**

| Activity | Parameters | | | Aggregate costs | Item explanation |
|---|---|---|---|---|---|
| | Year | Rate | Unit | | |
| **Global** | --- | | | | Item explanation |
| Crew hourly | --- | 110 | $ | --- | Hourly cost of crew (calculated field) |
| Crew daily | --- | 880 | $ | --- | Daily cost of crew (calculated field) |
| Labor hour | --- | 30 | $/hr | --- | Enter per-hour cost of labor |
| Tech hour | --- | 50 | $/hr | --- | Enter per-hour cost of technician / supervisor |
| Crew comp. | --- | 3 | persons | --- | Enter crew size |
| Mgmt hour | --- | 100 | $/hr | --- | Enter per-hour cost of management |
| Area | --- | 1 | ac | --- | Enter total project area |
| Fencing | --- | No | On/Off | --- | |
| Discount rate | --- | 8 | % | --- | Enter expected discount rate |

### *4.1.1.2. Propagation and establishment*

Starting any forestry project is always the most expensive component of the project (§4.1.6.2), with capital outlay carried over the course of the rotation. The core model requires as input the per-seedling cost for each species (Table 4.1.3), the planting density on a species basis, costs associated with site preparation, and planting rates (Table 4.1.4). The models presented in this section assume a site preparation cost of $1,100 per acre, reflecting current estimates for manual site preparation costs. Mechanical site preparation (e.g. with the Gyro Trac machine) is estimated to cost $1,055, so these models can be viewed as essentially congruent for both site preparation methods. Collectively, these prices may be highly variable with time, so while this FMP includes a price scale for contractor services and seedling prices as a derived from silvicultural regime literature (§1.4), financial model outcomes should be recalculated with the most recent data in every case.

**Table 4.1.3. Seedling cost input parameters.**

| Activity | Parameters | | | Aggregate costs | Item explanation |
|---|---|---|---|---|---|
| | Year | Rate | Unit | | |
| **Propagation** | **1** | | | **$3,343.00** | Total seedling cost (calculated field) |
| Over 1 | | 25.00 | $/sdlg | $750.00 | Enter price per seedling, 0 if unused |
| Over 2 | | 2.50 | $/sdlg | $175.00 | Enter price per seedling, 0 if unused |
| Over 3 | | 0.00 | $/sdlg | $0.00 | Enter price per seedling, 0 if unused |
| Under 1 | | 5.50 | $/sdlg | $2,398.00 | Enter price per seedling, 0 if unused |
| Under 2 | | 0.00 | $/sdlg | $0.00 | Enter price per seedling, 0 if unused |
| Under 3 | | 0.00 | $/sdlg | $0.00 | Enter price per seedling, 0 if unused |
| Windbreak | | 0.00 | $/sdlg | $0.00 | Enter price per seedling, 0 if unused |
| Ground | | 20.00 | $/lb seed | $20.00 | Enter price per lb of seed, 0 if unused |

**Table 4.1.4. Site preparation, planting rate, and planting density input parameters.**

| Activity | Parameters Year | Rate | Unit | Aggregate costs | Item explanation |
|---|---|---|---|---|---|
| **Establishment** | **1** | | | **$2,580.60** | Total establishment cost (calculated field) |
| Site preparation | 1 | 1843.6 | $ | | Site prepration subtotal (calculated field) |
| Machine rate | | 135 | $/hr | | Enter per hour cost of mini excavator |
| Clear pace | | 0.125 | ac/hr | | Enter area cleared / treated per hour by crew |
| Chemical app | | 240 | $/ac | | Enter per acre cost cut-stump / frill herbicide |
| Machine prep | | 100 | unit/hr | | Enter holes / hr by excavator (zero manual) |
| Manual prep | | 60 | unit/hr | | Enter holes/ hr by crew (zero machine) |
| Average density | 1 | 536 | tree/ac | | Cumulative density (calculated field) |
| Density O1 | | 30 | tree/ac | $1,843.60 | Enter trees per acre, 0 if unused |
| Density O2 | | 70 | tree/ac | | Enter trees per acre, 0 if unused |
| Density O3 | | 0 | tree/ac | | Enter trees per acre, 0 if unused |
| Density U1 | | 436 | tree/ac | | Enter trees per acre, 0 if unused |
| Density U2 | | 0 | tree/ac | | Enter trees per acre, 0 if unused |
| Density U3 | | 0 | tree/ac | | Enter trees per acre, 0 if unused |
| Density W | | 0 | trees | | Enter trees per acre, 0 if unused |
| Seed weight G | | 1 | lbs/ac | | Enter weight of seeds per acre, 0 if unused |
| Planting | 1 | 737.00 | $ | | Planting labor costs (calculated field) |
| Total trees | 1 | 536 | trees | $737.00 | Total number of trees to plant (calculated field) |
| Planting rate | | 80 | tree/hr | | Number of trees planted per hour by crew |

### *4.1.1.3. Maintenance: irrigation, silviculture, and harvest costs*

Silvicultural regimes prescribe a variety of activity levels depending on species. For example, irrigation, fertilizer application, form control, pest control, weed control, and fruit harvesting (Table 4.1.5) are all annual requirements for a complex agroforestry system. In an agroforestry model, these activities incur considerable cost that must be offset by productivity. In contrast, timber regimes only require fertilizer application, form control, and weed control during the first two years, with essentially no maintenance required once the stand has been established. A critical aspect of maintenance is the cost associated with harvesting. Although harvesting is the source of revenue (§4.1.1.4), labor and transportation costs must be incurred before income can be acquired. The cost levels for these activities vary widely by species and complexity of the system.

**Table 4.1.5. Cost input parameters for irrigation, silviculture, and harvesting. Some controls are pre-set by selections elsewhere. For example, irrigation necessity is selected in the global parameter set, and if unnecessary automatically sets irrigation costs to zero.**

| Activity | Parameters | | | Aggregate costs | Item explanation |
|---|---|---|---|---|---|
| | Year | Rate | Unit | | |
| **Irrigation** | **1-20** | | | **Distributed** | Item explanation |
| Materials | 1 | 1331.71 | $ | $2,651.71 | Cost of irrigation (calculated field) |
| Installation | 1 | 1320 | $ | | Irrigation installation cost (calculated field) |
| Maintenance | 20 | 500 | $/yr | $500.00 | Enter annual cost of irrigatio maintenance |
| Water charges | 20 | 278.72 | $/yr | $278.72 | Enter annual per-acre water costs |
| **Silviculture** | **2-20** | | | **Distributed** | Item explanation |
| Fertilizer estab. | 4 | 120.00 | $/ac | $120.00 | Enter annual fertilizer costs, years 1 - 4 |
| Fertilizer maint. | 5-20 | 300.00 | $/ac | $300.00 | Enter annual fertilizer costs, years 4 and beyond |
| Form control | 5 | 1500 | $/ac/yr | $1,500.00 | Enter annual pruning costs, years 1 - 5 |
| Pest control | 10 | 472.40 | $/yr | $472.40 | Enter annual pest control costs |
| Weed control | 5 | 330 | $/yr | $330.00 | Enter annual weed control costs |
| **Harvesting** | **4-20** | | | **Distributed** | Item explanation |
| Over 1 | 4 | 2697.30 | $/ac | $2,697.30 | Harvesting costs, overstory 1 (calculated field) |
| Over 2 | 7 | 245.00 | $/ac | $245.00 | Harvesting costs, overstory 2 (calculated field) |
| Over 3 | 10 | 0.00 | $/ac | $0.00 | Harvesting costs, overstory 3 (calculated field) |
| Under 1 | 10 | 1587.04 | $/ac | $1,587.04 | Harvesting costs, understory 1 (calculated field) |
| Under 2 | 10 | 0.00 | $/ac | $0.00 | Harvesting costs, understory 2 (calculated field) |
| Under 3 | 10 | 0.00 | $/ac | $0.00 | Harvesting costs, understory 3 (calculated field) |
| Transport | | 312.00 | $/yr | $312.00 | Enter annual transport-assocaited costs |

### *4.1.1.4. Productivity and harvesting revenues*

The amount of fruit produced by a given agroforestry crop, or the volume of wood (Siddiqui *et al.* 2010) that results from timber tree growth, enters the model in the form of a yield function or growth curve (Figure 4.1.1). Production units (e.g. pounds of fruit per tree or board feet of timber per tree) are converted into monetary figures by applying a unit price production per acre. Some complexity may be required to arrive at realistic productivity estimates. For example, annual mortality rates reduce timber stand density, volume may be calculated as a multi-parameter function of age, diameter, and height; merchantable volume is considerably lower than standing volume due to saw kerf. The purpose of this core financial model is not to estimate costs for every possible prescription, but rather to provide a framework for calculating costs that may be used by the management entity responsible for implementation. Where available, the silvicultural regimes for each species provide a first order approximation for model input parameters, but costs for particular configurations not reviewed in case studies (§4.2) must be calculated.

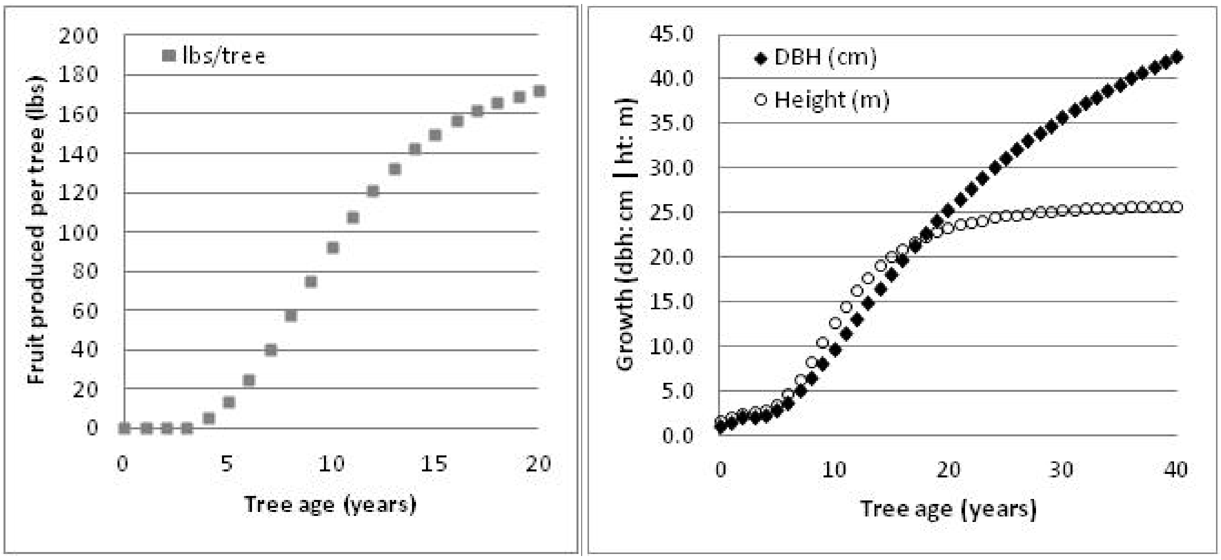



**Figure 4.1.1. Productivity of fruit crops (left) or timber stands (right) enters the core financial model in the form of a growth curve.**

#### *4.1.1.5. Indirect costs*

Several costs are not related to establishment, maintenance, or production in any functional way, but must nonetheless feature in the model. These indirect costs include transportation (e.g. of machines for site preparation), fencing, or, for private contractors, various taxes or fees that might be associated with harvesting licenses. Unforeseen indirect costs may be added to the model.

### 4.1.2. Performance metrics

#### *4.1.2.1. Profitability indicators*

Three general output elements in the core financial model (net cash flow, internal rate of return, and net present value) indicate whether agroforestry species configuration or a timber planting density has the potential to be profitable given the set of input assumptions. The net cash flow may be the most useful performance metric for watershed conservation plantings. These activities are not expected to be profitable, but the funding agencies that support the work will require accurate assessment of project costs. For timber or agroforestry activities, a metric for investment performance is the internal rate of return (IRR), which is a percentage measure of the difference between negative and positive cash flows as valued over the life of the investment; higher IRR percentage values indicate greater profitability. The net cash flows used to calculate IRR are also embodied in the concept of net present value (NPV), which is the project value in present-day capital accounting for a given discount rate applied over the course of the investment. This is a dollar value expression of the IRR, and again higher values mean greater profitability.

#### *4.1.2.2. Rotation length*

The most significant costs of any timber or agroforestry project are typically propagation and establishment because these activities are proportionally expensive and because they occur at the beginning of the rotation. Expenses incurred early in the rotation have a higher cost of capital than later expenses because the discount rate on projected cash flows is applied over a longer period of time. Extended rotations with late harvests incur the most cost of capital, whereas projects in which harvests begin shortly after establishment become profitable more quickly. For example, the mahogany case study below (§4.2.1) does not show a positive IRR until nearly 40 years after planting when the trees grow to sufficient size to merit harvest. Establishment costs are therefore borne for 40 years before revenues begin. In contrast, the cacao agroforestry systems (§4.2.2, §4.2.3), where harvesting begins in the fourth year, become profitable as early as the 15th year because revenues offset the capital cost of establishment. This earlier profitability, however, requires far greater annual expenditures and management effort.

#### *4.1.2.3. Scale dependency*

It is important to note that net cost and IRR may be independent of project acreage in some cases (e.g. where all costs are a 1:1 linear function of scale) but dependent in others (e.g. where certain costs increase in a non-linear way); NPV and per-acre NPV are always acreage-dependent. Certain costs in the core model are always directly proportional to acreage and thus increase in a 1:1 fashion with project scale. Other costs, such as management, and indirect costs, are less then proportional to varying degrees, meaning that additional acreage increases costs either marginally or not at all. For example, management costs increase at about 10% with acreage, whereas per-acre costs of perimeter fencing decrease with the square of the area. Irrigation costs may increase more than 1:1, and may moreover be nonlinear, with the result that projects reach a maximum NPV at intermediate acreage. This typically happens for projects larger than anything that would be proposed for the WFR, however. Overall, when a project does not require irrigation or fencing and when acreage is intermediate, per acre net costs and IRR are constant while NPV increases with scale. Small acreages may not be profitable, and depending on the suite of management and indirect costs, profitability may achieve a maximum value at intermediate acreage. In general, very small projects, such as those that will be installed during early pilot studies (§5.1), have little capacity to be profitable, and their value lies in optimizing procedures for future work. Later projects (§5.2) implemented using pilot project outcomes on larger acreages do have the potential to be cost effective.

#### *4.1.2.4. Capitalization*

Stakeholders, contractors, community groups, or other potential forest management entities (FME) may approach working in the WFR from one of two general directions. Certain FME may be well capitalized and therefore capable of bearing establishment costs while waiting for revenues from forest products. Other FME may be poorly capitalized but may nonetheless be equipped with abundant cost-free labor resources (e.g. community groups, individual stakeholders). This latter type of FME cannot be expected to complete the project establishment phase at the rate outlined in this FMP. Rather, these FME should follow the broad outlines of the silvicultural prescriptions, but would be constrained to manual site preparation options and projects in limited areas. The land tenure structure for the WFR should be prepared to accommodate interested stakeholders with both types of capitalization, particularly since the "cash rich" are likely to be viewed as exploitative if the "time rich" are not allowed fair access to land.

### 4.1.3. Contractors and price lists

Material and operational costs used to develop the financial model and case studies presented here were derived from price lists furnished by local contractors. Many of the prescriptions defined in this FMP can be implemented by contractors within the Waimānalo Valley, which include numerous nurseries, farmers, and tree service professionals. For services unavailable locally, contractors exist on Oʻahu or the neighbor islands. Nursery contractors are among the best represented in the Waimānalo community, with businesses either directly adjacent to the WFR or only a few miles away (Table 4.1.6). For example, Frankie's Nursery, located on Mahiku Place and sharing a TMK boundary with the WFR, can produce almost 50% of the fruit tree species proposed for agroforestry (Table 3.3.6), while Koba's Nursery and Akamai Nursery, both less than two miles from the WFR, produce a wide range of fruit, timber, and native Hawaiian trees. Producers of native Hawaiian plant species are chiefly located outside of Waimānalo Valley, however, with some of the best contractors on neighbor islands (Table 4.1.6). For timber seedlings, the DLNR DOFAW nursery, located in Kamuela, Hawai‘i Island, is a cost effective option and also produces many of the species recommended in this FMP. Site preparation for every aspect of the project will require crews trained in frill application of herbicides as well as chainsaw operation, cut stump herbicide application, and windrowing; this service is provided by the Waimanlo company Arborscapes, LLC (Table 4.1.6), as well as by contractors throughout O‘ahu; herbicides, pesticides, and fertilizers necessary for site preparation, establishment, and maintenance are available from Crop Production Services. Of the contractors listed here (Table 4.1.6), several have online price lists, or will provide quotes on request; these prices were used in the following case studies (§4.2). Because pricing is subject to unpredictable change, rather than including price lists in this FMP, contractor contact information is provided; the internet addresses will provide updated price lists in a more useful format.

**Table 4.1.6. Contractors able to complete various aspects of this FMP are available in Waimānalo or elsewhere in Hawaii. Listed contractors would be capable of completing this FMP, although other contractors may be suitable.**

| Company | Services | Telephone | Internet |
|---|---|---|---|
| Frankie's Nursery | Fruit trees, rare timber | (808) 259-8737 | www.frankiesnursery.com/ |
| Koba's Nursery | Fruit trees, native species | (808) 259-5954 | --- |
| Akamai Nursery | Fruit trees, native species | (888) 771-2399 | www.akamailandscape.net/ |
| Hui ku Maoli Ola | Native species | (808) 235-6165 | www.hawaiiannativeplants.com/ |
| Native Nursery | Native species | (808) 878-8276 | www.mauinativenursery.com/ |
| Kamuela State Tree Nursery | Timber, native species | (808) 887 6061 | hawaii.gov/dlnr/dofaw/contact |
| Arborscapes | Tree removal, site prep. | (808) 744-8200 | www.arborscapeshawaii.com |
| Tree Works | Tree removal, site prep. | (808) 885-5789 | www.treeworksinc.com |
| Hawaii Ag. Research Center | Research and development | (808) 677-5541 | www.harc-hspa.com/ |
| Crop Production Services | Fertilizer and herbicides | (808) 454-0041 | www.cpsagu.com |

## 4.2. Case studies

The combinations of activity, acreage, and species assemblages are numerous, so cost assessments will be explored via case studies for simple systems (e.g. a mahogany timber planting, §4.2.1), two-species systems (e.g. a cacao planting with one overstory species, §4.2.2), and complex systems (e.g. cacao, an overstory fruit tree, and an overstory shade tree, §4.2.3). Reviews of potentially productive configurations are available in the agroforestry literature (§1.4), and where possible with growth and yield functions for financial model input.

### 4.2.1. Mahogany timber planting

This case study is intended to serve as the model for any prescription in which a single species, or a group of species with comparable silvicultural regimes (referred to as a forest management class, §2), is planted within a matrix of extant overstory that has been cleared by either (1) mechanized chipping with a Gyro Trac or (2) felling, windrowing, and cut-stump treatment. These site preparation options differ minimally in terms of cost ($1,055 per acre for mechanized, $1,100 per acre for manual windrowing), and all of the example models use the slightly higher value to derive a more conservative result. It must be noted that terrain out of line with expectations may substantially increase the costs of either option. The third site preparation option, killing trees in place by frill treatment and planting amongst the dead stems, is not given further attention here since it is a low-cost, rather dangerous option suited only for contractors or groups that are under-capitalized. The input, growth and yield curves, and output can be adjusted to allow the model to calculate costs, IRR, and NPV for timber species as well as single-species fruit tree plantings. In addition, the model can be used to predict costs for native species restoration projects, in which case the IRR and NPV output is ignored[9]. The simplicity of single species or single class systems reduces dramatically the number of required input fields. The model is fully parameterized using cost per seedling, site preparation and planting costs, silvicultural input costs, harvesting and transport costs, and taxes and fees.

Productivity parameters enter the model via growth (Eq. 1, 2) and volume (Eq. 3, 4) functions derived for the species, although in this case for Indonesia (Krisnawati *et al.* 2011). Although the precise parameter set that limits growth may differ slightly between e.g. Indonesia (Krisnawati *et al.* 2011) and Hawai'i, differences exceeding 10% are not expected, and the functional form will remain qualitatively similar. Diameter growth is modeled as an inverse-log function of age,

EXP(A-(B/Age))+C (Equation 1)

where the upper limit to diameter and the shape of early growth are controlled by empirical parameters A (4.25), B (22), and C (2). Height is also expressed as a function of age, although the particular function uses age-derived diameter as a proxy:

D*((1-(EXP(E*Diameter)))^F) (Equation 2)

where the model parameters (D: 25; E: -0.10538; F: 1.790226) are empirically determined. The parameter sets for both equations should be viewed as a first approximation. Monitoring growth rates in the WFR after planting (§6) will provide data with which to validate the parameters, making adjustments as necessary using standard nonlinear regression techniques. Total tree volume may be estimated either as a function solely of diameter (Eq. 3) or both diameter and height (Eq. 4):

10^(-0.5157+2.1623*LOG10(Diameter)) (Equation 3)

10^(-1.007+2.0086*LOG10(Diameter)+0.6156*LOG10(Height)) (Equation 4)

where total volume is expressed as cubic meters (Table 4.2.1). Due to losses from saw blade width, merchantable volume is approximately 50% to 60% of total standing volume (here, 60%), which at a conservative price point of $1.00 per board-foot (bf), yields $343.63 per tree at age 40 (Table 4.2.1).

**Table 4.2.1. Factors necessary to develop a growth curve include unit pricing, stand age, tree growth rates or productivity expectations, and stand density. Merchantable volume is approximately 60% of total volume due to losses during processing; valuation is a conservative $1.00 bf$^{-1}$ stumpage.**

| Year | tpa | DBH (cm) | Height (m) | Vol f(D) | Vol f(D,H) | Saw vol (bf) | bf/tree | $/tree | $/ac |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 435 | 1.0 | 2 | 0 | 0 | 0 | 0 | $0 | $15 |
| 1 | 413 | 1.5 | 2 | 1 | 0 | 0 | 0 | $0 | $37 |
| 2 | 393 | 2.0 | 3 | 1 | 1 | 0 | 0 | $0 | $71 |
| 3 | 373 | 2.0 | 3 | 1 | 1 | 0 | 0 | $0 | $71 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 38 | 102 | 41.3 | 26 | 951 | 1279 | 325 | 325 | $325 | $33,114 |
| 39 | 101 | 41.9 | 26 | 981 | 1317 | 334 | 334 | $334 | $33,758 |
| 40 | 100 | 42.4 | 26 | 1010 | 1354 | 344 | 344 | $344 | $34,363 |

This scenario presents a simple case where all of the harvestable trees are cut at the same time, and where a reasonable harvest time density is 130 trees per acre (tpa). Variations on this scenario are possible, as it may be

[9] Quantitative economic value can be assigned to native species assemblages e.g. when they provide ecosystem services such as erosion mitigation or aesthetics . Both of these services are relevant to the WFR, but it is beyond the scope of this FMP to explore the economic valuation of ecosystem services.

the case that survival exceeds 130 tpa but only 130 trees are mature by the 45 year rotation deadline. If selection harvesting is conducted over several years, the number of trees per acre harvested must be reduced, but NPV and IRR may actually increase by offsets from further tree growth since the stand has perhaps not reached financial maturity (i.e. if growth rate acceleration at age 45 outweighs the accumulated cost of capital).

Financial performance of the timber plantation can be assessed by several measures, including establishment costs (which are incurred during the first two years of the project), per-acre establishment costs, IRR assuming a 45-year rotation, and per-acre NPV (Table 4.2.2). The most important feature of this model is the progressive reduction in per-acre establishment costs as project acreage increases, reflecting less than proportional increases in management costs, as well as reduced influence of indirect costs that are independent of acreage (e.g. machine transport). From the viewpoint of profitability, establishing less than 10 acres of timber is not advised because NPV would be negative (Table 4.2.2) due to the influences of indirect costs. On the other hand, any project larger than 25 acres would be potentially profitable, and a 50-acre project represents a reasonable investment with an 8.1% IRR and per-acre NPV of $112 (Table 4.2.2). For annual budgets through 20 years, consult §4.3.1.

**Table 4.2.2. Planting costs associated with establishing *Swietenia macrophylla*. Establishment costs, IRR, and NPV are presented for project sizes varying from one acre through 20 acres. Financial maturity (net profitability) occurs between 35 and 40 years, so IRR and NPV are presented for a 40 year rotation.**

| | Acreage | | | | |
|---|---|---|---|---|---|
| Costs | 1 | 5 | 10 | 25 | 50 |
| Year 1 | -$5,018 | -$15,650 | -$28,940 | -$68,809 | -$135,258 |
| Year 2 | -$660 | -$2,580 | -$4,980 | -$12,180 | -$24,180 |
| **Total:** | **-$5,678** | **-$18,230** | **-$33,920** | **-$80,989** | **-$159,438** |
| Year 1 $ac^{-1}$ | -$5,018 | -$3,130 | -$2,894 | -$2,752 | -$2,705 |
| Year 2 $ac^{-1}$ | -$660 | -$516 | -$498 | -$487 | -$484 |
| **Total:** | **-$5,678** | **-$3,646** | **-$3,392** | **-$3,240** | **-$3,189** |
| IRR 45 | 6.6% | 7.7% | 7.9% | 8.1% | 8.1% |
| NPV 45 $ac^{-1}$ | -$2,302 | -$331 | -$85 | $63 | $112 |

Results from this financial model are applicable both to the early stages of the project (Phase I, §5.1) as well as to later stages (Phase II, §5.2). In particular, early stages would require small-scale pilot studies where costs should be predicted using the single acre case. Profitability would not be the intent of such pilot studies; rather, these projects would (1) refine cost assessments, (2) optimize species-site matching, and (3) accumulate tree growth data with which subsequent iterations of the financial models could be improved. Although the real establishment cost (also real IRR and NPV) of larger scale projects may differ slightly from the model, this FMP assumes costs on par with the 20 acre model, meaning that establishment costs for Phase II implementation of timber plantings are valued at $2,047 $ac^{-1}$ (Table 4.2.3). Establishment costs of planting native Hawaiian species in the watershed zones (Table 4.2.3) can be derived using the same model, with the exception of revenues and harvesting costs, and without calculating IRR or NPV. The scale of watershed planting projects will likely be constrained by topography as well as funding. It is probable that small areas would be planted by several groups or stakeholders, so for planning purposes, per-acre costs are listed at two levels: small projects of one acre or less would cost $7,758 $ac^{-1}$, while larger projects of approximately two acres would cost $4,795 $ac^{-1}$ (Table 4.2.3).

**Table 4.2.3. Costs of establishing endemic species for projects of several scales. Average seedling cost is set to $5.50 and planting density at 500 tpa, which reflects 2013 parameters for comparable projects. Profitability is not the objective for watershed plantings, so IRR and NPV are not presented.**

| | Acreage | | | | |
|---|---|---|---|---|---|
| Costs | 1 | 2 | 5 | 10 | 20 |
| Year 1 | $7,188 | $11,379 | $23,955 | $44,914 | $86,833 |
| Year 2 | $570 | $960 | $2,130 | $4,080 | $7,980 |
| **Total:** | $7,758 | $12,339 | $26,085 | $48,994 | $94,813 |
| Year 1 $ac^{-1}$ | $7,188 | $5,690 | $4,790.99 | $4,491 | $4,341.64 |
| Year 2 $ac^{-1}$ | $570 | $480 | $426 | $408 | $399 |
| **Total:** | $7,758 | $6,170 | $5,217 | $4,899 | $4,741 |

## 4.2.2. Jackfruit (*Artocarpus heterophyllus*) single species plantation

This and the following case studies (§4.2.3 - §4.2.6) rely on the same basic model input in regards to seedling cost, density, silviculture, indirect costs, management and harvesting costs, and revenues. Rather than modeling production of timber, however, these cases show potential fruit production for systems of varying complexity. Although timber could be a byproduct of some agroforestry configurations that contain overstory species with high value wood, the agroforestry financial models yield results for net profitability on a rotation of fruit production rather than timber. Forecasting per-acre fruit production is accomplished by adjusting a log-normal function that describes per-tree productivity. Yields are constrained by the growth function at early ages, and approach maximum rates by average date of tree maturity (Table 4.2.4). For these case studies, parameter data are derived from a variety of sources (Martin 1997, Elevitch *et al*. 2006).

**Table 4.2.4. Productivity of jackfruit through first production and through 20 years. Valuation of the crop is based on a per-lb price of $0.40, which is the approximate state-wide price as of 2013.**

| Year | lbs/tree | $/tree | $/ac |
|---|---|---|---|
| 0 | 0.00 | $0.00 | $0.00 |
| 1 | 0.00 | $0.00 | $0.00 |
| 2 | 0.00 | $0.00 | $0.00 |
| 3 | 0.00 | $0.00 | $0.00 |
| 4 | 37.68 | $15.07 | $1,055.12 |
| 5 | 47.10 | $18.84 | $1,318.91 |
| 6 | 58.88 | $23.55 | $1,648.63 |
| ... | ... | ... | ... |
| 17 | 494.53 | $197.81 | $13,846.87 |
| 18 | 543.44 | $217.38 | $15,216.34 |
| 19 | 597.19 | $238.88 | $16,721.25 |
| 20 | 656.25 | $262.50 | $18,375.00 |

Whereas cumulative establishment costs for one or two acres yield negative NPV, any plantation size exceeding three acres begins to yield NPV above $11,700, which corresponds to an IRR of 8.7% (Table 4.2.5). Thus, plans with limited funding (§5.2, §5.3) may be most suitable to establishment by entities with no profit objective (e.g. the State of Hawai'i for community programs). In contrast, plans with sufficient funding (§5.4, §5.5) to establish more than three acres have the potential to be profitable, and are better suited to permitted or licensed contractors granted long-term harvesting rights. For annual budgets through 20 years, consult §4.3.2..

**Table 4.2.5. Costs of establishing *Artocarpus heterophyllus* (jackfruit). For a 10 acre project, revenues exceed expenditures in the 9$^{th}$ year, but profitability is not realized until the 15$^{th}$ year.**

| Average Net | Acreage | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 7.5 | 10 |
| Year 1 | -$11,922 | -$19,083 | -$26,910 | -$44,564 | -$70,379 | -$100,358 |
| Year 2-5 | -$4,763 | -$6,776 | -$8,788 | -$12,814 | -$17,846 | -$22,878 |
| Year 6-10 | -$3,592 | -$3,280 | -$2,967 | -$2,342 | -$1,560 | -$778 |
| Year 11-15 | $1,050 | $5,824 | $10,599 | $20,148 | $32,084 | $44,021 |
| Year 16-20 | $4,408 | $12,542 | $20,675 | $36,942 | $57,276 | $77,610 |
| **Total:** | **-$21,644** | **$29,247** | **$79,472** | **$177,923** | **$297,239** | **$412,391** |
| Year 1 $ac^{-1}$ | -$11,922 | -$9,541 | -$8,970 | -$8,913 | -$9,384 | -$10,036 |
| Year 2-5 $ac^{-2}$ | -$4,763 | -$3,388 | -$2,929 | -$2,563 | -$2,379 | -$2,288 |
| Year 6-10 $ac^{-3}$ | -$3,592 | -$1,640 | -$989 | -$468 | -$208 | -$78 |
| Year 11-15 $ac^{-4}$ | $1,050 | $2,912 | $3,533 | $4,030 | $4,278 | $4,402 |
| Year 16-20 $ac^{-5}$ | $4,408 | $6,271 | $6,892 | $7,388 | $7,637 | $7,761 |
| **Total:** | **-$21,644** | **$14,624** | **$26,491** | **$35,585** | **$39,632** | **$41,239** |
| IRR 20 | --- | 3.0% | 5.5% | 7.4% | 8.2% | 8.3% |
| NPV 20 $ac^{-1}$ | -$32,748 | -$8,085 | -$114 | $5,813 | $8,215 | $8,947 |

### 4.2.3. Avocado (*Persea americana*) single species plantation

Avocado agroforestry may capture the interest of multiple community groups, from those who want to establish long-term food sources for the human population, to those who want to augment food for hunted pig populations. Regardless of whether these land uses are mutually exclusive or currently allowed, these objectives may be compatible in the future, and establishing a substantial area of avocado plantings could bring the community together. Productivity of avocado trees (Table 4.2.6) was derived from conservative production quotas (CTAHR 2x). Small acreages (less than five) are again unlikely to be productive (

Table 4.2.7), so entities with no profit objective (State of Hawaii, Waimānalo community groups) would be candidates for working at this scale. At acreages above five, NPV becomes increasingly positive and could merit establishment by permitted or licensed contractors. For annual budgets through 20 years, consult §4.3.2.

| Year | lbs/tree | $/tree | $/ac |
|---|---|---|---|
| 0 | 0.00 | $0.00 | $0.00 |
| 1 | 0.00 | $0.00 | $0.00 |
| 2 | 0.00 | $0.00 | $0.00 |
| 3 | 0.00 | $0.00 | $0.00 |
| 4 | 37.68 | $15.07 | $1,055.12 |
| 5 | 47.10 | $18.84 | $1,318.91 |
| 6 | 58.88 | $23.55 | $1,648.63 |
| … | … | … | … |
| 17 | 494.53 | $197.81 | $13,846.87 |
| 18 | 543.44 | $217.38 | $15,216.34 |
| 19 | 597.19 | $238.88 | $16,721.25 |
| 20 | 656.25 | $262.50 | $18,375.00 |

**Table 4.2.6. Productivity of avocado through first production and through 20 years. Valuation of the crop is based on a per-lb price of $1.20.**

| Average Net | Acreage | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 7.5 | 10 |
| Year 1 | -$13,822 | -$22,883 | -$32,610 | -$54,064 | -$84,629 | -$119,358 |
| Year 2-5 | -$5,343 | -$7,935 | -$10,528 | -$15,713 | -$22,194 | -$28,675 |
| Year 6-10 | -$2,963 | -$2,022 | -$1,080 | $803 | $3,157 | $5,511 |
| Year 11-15 | $2,389 | $8,504 | $14,618 | $26,847 | $42,133 | $57,419 |
| Year 16-20 | $4,949 | $13,623 | $22,297 | $39,645 | $61,329 | $83,014 |
| **Total:** | **-$13,317** | **$45,901** | **$104,453** | **$219,558** | **$359,692** | **$495,660** |
| Year 1 $ac^{-1}$ | -$13,822 | -$11,441 | -$10,870 | -$10,813 | -$11,284 | -$11,936 |
| Year 2-5 $ac^{-2}$ | -$5,343 | -$3,968 | -$3,509 | -$3,143 | -$2,959 | -$2,868 |
| Year 6-10 $ac^{-3}$ | -$2,963 | -$1,011 | -$360 | $161 | $421 | $551 |
| Year 11-15 $ac^{-4}$ | $2,389 | $4,252 | $4,873 | $5,369 | $5,618 | $5,742 |
| Year 16-20 $ac^{-5}$ | $4,949 | $6,811 | $7,432 | $7,929 | $8,177 | $8,301 |
| **Total:** | **-$13,317** | **$22,951** | **$34,818** | **$43,912** | **$47,959** | **$49,566** |
| IRR 20 | --- | 4.1% | 6.3% | 8.0% | 8.6% | 8.7% |
| NPV 20 $ac^{-1}$ | -$29,931 | -$5,268 | $2,703 | $8,631 | $11,032 | $11,765 |

**Table 4.2.7. Costs of establishing *Persea americana* (avocado). For a 10 acre project, revenues exceed expenditures in the 8th year, but profitability is not realized until the 14th year.**

## 4.2.4. Cacao (*Theobroma cacao*) with single overstory species (*Inga edulis*)

Agroforestry systems that most closely reflect natural forests will include consist of overstory species that are less tolerant of shade, understory species that are shade tolerant, and some form of groundcover. Complementary species selection should enable indefinite coexistence of each vegetation stratum, with productivity from all layers (**Table 4.2.8**). In a dual species system with an overstory of *I. edulis* and an understory of *T. cacao*, productivity should begin in the fifth year after planting, with the majority of revenues derived from the higher-value cacao, and only incidental revenues from sales of Inga seed pods (Table 4.2.8).

| *Inga edulis* | | | | *Theobroma cacao* | | | |
|---|---|---|---|---|---|---|---|
| Year | lbs/tree | $/tree | $/ac | Year | lbs/tree | $/tree | $/ac |
| 0 | 0.00 | $0.00 | $0.00 | 0 | 0.00 | $0.00 | $0.00 |
| 1 | 0.00 | $0.00 | $0.00 | 1 | 0.00 | $0.00 | $0.00 |
| 2 | 0.00 | $0.00 | $0.00 | 2 | 0.00 | $0.00 | $0.00 |
| 3 | 0.00 | $0.00 | $0.00 | 3 | 0.00 | $0.00 | $0.00 |
| 4 | 2.50 | $2.50 | $175.00 | 4 | 1.50 | $2.70 | $1,177.20 |
| 5 | 5.00 | $5.00 | $350.00 | 5 | 3.50 | $6.30 | $2,746.80 |
| 6 | 10.00 | $10.00 | $700.00 | 6 | 5.00 | $9.00 | $3,924.00 |
| ... | ... | ... | ... | ... | ... | ... | ... |
| 17 | 12.00 | $12.00 | $840.00 | 17 | 5.60 | $10.08 | $4,394.88 |
| 18 | 12.00 | $12.00 | $840.00 | 18 | 5.60 | $10.08 | $4,394.88 |
| 19 | 12.00 | $12.00 | $840.00 | 19 | 5.60 | $10.08 | $4,394.88 |
| 20 | 12.00 | $12.00 | $840.00 | 20 | 5.60 | $10.08 | $4,394.88 |

**Table 4.2.8. Productivity of *I. edulis* and *T. cacao* through first production and through 20 years. Valuation is based on a per-lb price of $1.00 for Inga pods (fresh) and $1.80 for cacao (unprocessed wet beans).**

**Although revenues generated early in the rotation may be positive (Table 4.2.8), cost of capital and ongoing maintenance expenditures allow net profitability only by the 14th year for a 10 acre plantation (Table 4.2.8). For plantations of five acres, NPV remains negative through 20 years, meaning that plantations larger than five acres are required for the project to be ultimately profitable. Positive returns (IRR up to 6.2%) may be achieved with plantings that exceed 10 acres (**

Table 4.2.9), where economy of scale is realized for area-based costs. For annual budgets through 20 years, consult §4.3.3.

| Average Net | Acreage | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 7.5 | 10 |
| Year 1 | -$20,238 | -$34,133 | -$48,694 | -$79,815 | -$122,465 | -$169,280 |
| Year 2-5 | -$6,244 | -$9,739 | -$13,233 | -$20,222 | -$28,958 | -$37,694 |
| Year 6-10 | -$197 | $3,512 | $7,220 | $14,637 | $23,907 | $33,178 |
| Year 11-15 | $1,186 | $6,096 | $11,007 | $20,828 | $33,104 | $45,381 |
| Year 16-20 | $1,179 | $6,082 | $10,986 | $20,794 | $33,053 | $45,312 |
| **Total:** | **-$34,377** | **$5,363** | **$44,438** | **$120,587** | **$212,026** | **$299,301** |
| Year 1 $ac^{-1}$ | -$20,238 | -$17,066 | -$16,231 | -$15,963 | -$16,329 | -$16,928 |
| Year 2-5 $ac^{-2}$ | -$6,244 | -$4,869 | -$4,411 | -$4,044 | -$3,861 | -$3,769 |
| Year 6-10 $ac^{-3}$ | -$197 | $1,756 | $2,407 | $2,927 | $3,188 | $3,318 |
| Year 11-15 $ac^{-4}$ | $1,186 | $3,048 | $3,669 | $4,166 | $4,414 | $4,538 |
| Year 16-20 $ac^{-5}$ | $1,179 | $3,041 | $3,662 | $4,159 | $4,407 | $4,531 |
| **Total:** | **-$34,377** | **$2,682** | **$14,813** | **$24,117** | **$28,270** | **$29,930** |
| IRR 20 | --- | 0.6% | 3.2% | 5.1% | 5.9% | 6.1% |
| NPV 20 $ac^{-1}$ | -$42,065 | -$16,513 | -$8,245 | -$2,080 | $440 | $1,232 |

**Table 4.2.9. Costs of establishing a shaded cacao plantation with an overstory of *Inga edulis*. For a 10 acre project, revenues exceed expenditures in the 6th year, but profitability is not realized until the 14th year.**

### 4.2.5. Cacao (*Theobroma cacao*) with dual overstory

Only the number of different combinations of available species presents any inherent upper limit to the complexity of agroforestry prescriptions. This case study, where shade tolerant cacao is planted with a shade intolerant overstory of jackfruit and Inga, presents the basic financial model for systems where multiple crops are produced in each vegetation stratum. The chief differences between this and simpler plans are (1) tracking propagation and establishment costs for several species, (2) tracking different silvicultural prescriptions, and (3) tracking variable maturation dates and harvesting costs. To a large extent, average costs may be substituted for (1) and (2). The financial model encodes variable maturation dates by using separate productivity functions, while harvesting costs may be entered for up to three species (or three classes of comparable species).

From a financial perspective, increasing species diversity leads to a slight advantage (Table 4.2.10), and also represents a better risk management strategy should one of the overstory species perform below expectations. In comparison to the simpler cacao-Inga system where a five-acre plantation yields 5.2% IRR, the cacao-Inga-Jackfruit system achieves only a 5.0% IRR for a plantation of comparable size (Table 4.2.10). This slightly diminished return reflects higher management costs for the additional complexity, as well as unavoidable inefficiencies associated with mobilizing three procedurally dissimilar harvest operations. For annual budgets through 20 years, consult §4.3.4.

| Average Net | Acreage | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 7.5 | 10 |
| Year 1 | -$15,329 | -$25,169 | -$35,676 | -$58,688 | -$91,201 | -$127,879 |
| Year 2-5 | -$5,385 | -$8,020 | -$10,656 | -$15,926 | -$22,514 | -$29,102 |
| Year 6-10 | -$2,186 | -$467 | $1,253 | $4,691 | $8,989 | $13,287 |
| Year 11-15 | $435 | $4,594 | $8,754 | $17,073 | $27,473 | $37,872 |
| Year 16-20 | $1,820 | $7,365 | $12,911 | $24,001 | $37,864 | $51,727 |
| **Total:** | **-$36,524** | **$215** | **$36,289** | **$106,436** | **$190,373** | **$270,145** |
| Year 1 $ac^{-1}$ | -$15,329 | -$12,585 | -$11,892 | -$11,738 | -$12,160 | -$12,788 |
| Year 2-5 $ac^{-2}$ | -$5,385 | -$4,010 | -$3,552 | -$3,185 | -$3,002 | -$2,910 |
| Year 6-10 $ac^{-3}$ | -$2,186 | -$233 | $418 | $938 | $1,199 | $1,329 |
| Year 11-15 $ac^{-4}$ | $435 | $2,297 | $2,918 | $3,415 | $3,663 | $3,787 |
| Year 16-20 $ac^{-5}$ | $1,820 | $3,683 | $4,304 | $4,800 | $5,049 | $5,173 |
| **Total:** | **-$36,524** | **$108** | **$12,096** | **$21,287** | **$25,383** | **$27,014** |
| IRR 20 | --- | 0.0% | 2.9% | 5.0% | 5.8% | 6.1% |
| NPV 20 $ac^{-1}$ | -$41,231 | -$16,159 | -$8,051 | -$2,015 | $441 | $1,201 |

**Table 4.2.10. Costs of establishing a shaded cacao plantation with a multi-species overstory of *Inga edulis* and *Artocarpus heterophyllus*. Annual net costs transition from negative to positive in approximately the 7th year, but the 15th year is the first year of net profitability.**

## 4.3. Long term budgets

Annual budget plans are presented for projects at the 10 acre scale, including costs for each management activity in each year. Each long term budget spans sufficient duration to reveal both first productivity and first profitability. To assess project performance (IRR, NPV, first profitability) for each case study (§4.2), the cell values in these budget tables were recalculated using acreage varying from 1 to 10. In each case, costs of fencing were excluded from analysis. Although it is beyond the scope of this FMP to explore the complete behavior of each financial model, the relative potential for profitability is clear, and forms the basis for predicting outcomes for projects that span a range of scales.

### 4.3.1. Timber

*4.3.1.1. Honduran mahogany 1-45*

| Activity \| Year | 1 | 2 | 3 | … | 42 | 43 | 44 | 45 | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$9,080** | **$0** | **$0** | **…** | **$0** | **$0** | **$0** | **$0** | **$9,080** |
| Overstory | $9,080 | $0 | $0 | … | $0 | $0 | $0 | $0 | $9,080 |
| **Establishment** | **$12,500** | **$0** | **$0** | **…** | **$0** | **$0** | **$0** | **$0** | **$12,500** |
| Site preparation | $11,000 | $0 | $0 | … | $0 | $0 | $0 | $0 | $11,000 |
| Planting | $1,500 | $0 | $0 | … | $0 | $0 | $0 | $0 | $1,500 |
| **Silviculture** | **$4,600** | **$4,600** | **$0** | **…** | **$0** | **$0** | **$0** | **$0** | **$9,200** |
| Fertilization | $1,200 | $1,200 | $0 | … | $0 | $0 | $0 | $0 | $2,400 |
| Form control | $1,000 | $1,000 | $0 | … | $0 | $0 | $0 | $0 | $2,000 |
| Pest control | $1,000 | $1,000 | $0 | … | $0 | $0 | $0 | $0 | $2,000 |
| Weed control | $1,400 | $1,400 | $0 | … | $0 | $0 | $0 | $0 | $2,800 |
| **Harvesting** | **$0** | **$0** | **$0** | **…** | **$0** | **$0** | **$0** | **$84,233** | **$0** |
| Overstory | $0 | $0 | $0 | … | $0 | $0 | $0 | $83,233 | $0 |
| Transport, market | $0 | $0 | $0 | … | $0 | $0 | $0 | $1,000 | $0 |
| **Indirect costs** | **$2,000** | **$0** | **$0** | **…** | **$0** | **$0** | **$0** | **$2,000** | **$2,000** |
| Transport, machine | $2,000 | $0 | $0 | … | $0 | $0 | $0 | $2,000 | $2,000 |
| Taxes and fees | $25 | $25 | $25 | … | $25 | $25 | $25 | $25 | $1,000 |
| **Management** | **$760** | **$380** | **$0** | **…** | **$0** | **$0** | **$3,800** | **$21,058** | **$1,140** |
| Establishment | $380 | $0 | $0 | … | $0 | $0 | $0 | $0 | $380 |
| Silviculture | $380 | $380 | $0 | … | $0 | $0 | $0 | $0 | $760 |
| Harvesting | $0 | $0 | $0 | … | $0 | $0 | $3,800 | $21,058 | $0 |
| **Revenues** | **$0** | **$0** | **$0** | **…** | **$0** | **$0** | **$0** | **$1,075,830** | **$0** |
| Overstory | $0 | $0 | $0 | … | $0 | $0 | $0 | $1,075,830 | $0 |
| Costs (direct) | -$26,940 | -$4,980 | $0 | … | $0 | $0 | -$3,800 | -$105,292 | **-$141,011** |
| Costs (indirect) | -$2,000 | $0 | $0 | … | $0 | $0 | $0 | -$2,000 | **-$4,000** |
| Revenues: Rotation 40 | $0 | $0 | $0 | … | $0 | $0 | $0 | $1,075,830 | **$1,075,830** |
| Net | -$28,940 | -$4,980 | $0 | … | $0 | $0 | -$3,800 | $968,539 | **$930,819** |
| Annual gross margin | 0% | 0% | 0% | … | 0% | 0% | 0% | 90% | **0%** |
| Summed net | -$28,940 | -$33,920 | -$33,920 | … | -$33,920 | -$33,920 | -$37,720 | $930,819 | --- |

### 4.3.2. Overstory agroforestry

#### *4.3.2.1. Avocado 1-10*

| Activity \| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$38,700** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Overstory / ac | $3,850 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Groundcover / ac | $20 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Establishment** | **$10,097** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Site preparation | $9,135 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Planting | $963 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Irrigation** | **$56,486** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** |
| Materials | $37,922 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Construction | $13,200 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Maintenance | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 |
| **Silviculture** | **$4,500** | **$24,224** | **$24,224** | **$9,224** | **$16,200** | **$7,724** | **$3,000** | **$7,724** | **$3,000** | **$7,724** |
| Fertilization | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $3,000 | $3,000 | $3,000 | $3,000 | $3,000 |
| Form control | $0 | $15,000 | $15,000 | $0 | $15,000 | $0 | $0 | $0 | $0 | $0 |
| Pest control | $0 | $4,724 | $4,724 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 |
| Weed control | $3,300 | $3,300 | $3,300 | $3,300 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Harvesting** | **$0** | **$0** | **$0** | **$0** | **$4,319** | **$5,847** | **$8,249** | **$11,347** | **$14,841** | **$18,426** |
| Overstory / ac | $0 | $0 | $0 | $0 | $120 | $273 | $513 | $823 | $1,172 | $1,531 |
| Transport, market / ac | $0 | $0 | $0 | $0 | $312 | $312 | $312 | $312 | $312 | $312 |
| **Indirect costs** | **$1,025** | **$625** | **$625** | **$625** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** |
| Transport, machine | $1,025 | $625 | $625 | $625 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| **Management** | **$8,550** | **$3,800** | **$3,800** | **$3,800** | **$5,700** | **$5,700** | **$5,700** | **$7,600** | **$5,700** | **$5,700** |
| Establishment | $4,750 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 |
| Silviculture | $1,900 | $1,900 | $1,900 | $1,900 | $0 | $0 | $0 | $1,900 | $0 | $0 |
| Harvesting | $0 | $0 | $0 | $0 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 |
| **Revenues** | **$0** | **$0** | **$0** | **$0** | **$4,946** | **$11,247** | **$21,152** | **$33,927** | **$48,335** | **$63,120** |
| Overstory | $0 | $0 | $0 | $0 | $4,946 | $11,247 | $21,152 | $33,927 | $48,335 | $63,120 |
| Costs (direct) | -$118,333.29 | -$33,388 | -$33,388 | -$18,388 | -$31,583 | -$24,635 | -$22,313 | -$32,035 | -$28,905 | -$37,214 |
| Costs (indirect) | -$1,025 | -$625 | -$625 | -$625 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 |
| Revenues | $0 | $0 | $0 | $0 | $4,946 | $11,247 | $21,152 | $33,927 | $48,335 | $63,120 |
| Annual net | -$119,358 | -$34,013 | -$34,013 | -$19,013 | -$27,662 | -$14,413 | -$2,186 | $867 | $18,405 | $24,880 |
| Annual gross margin | --- | --- | --- | --- | -559% | -128% | -10% | 3% | 38% | 39% |
| Summed net | -$119,358 | -$153,371 | -$187,384 | -$206,397 | -$234,059 | -$248,473 | -$250,659 | -$249,792 | -$231,387 | -$206,507 |

### *4.3.2.2. Avocado 11-20*

| Activity \| Year | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$38,700** |
| Overstory / ac | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $3,850 |
| Groundcover / ac | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $20 |
| **Establishment** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$10,097** |
| Site preparation | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,135 |
| Planting | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $963 |
| **Irrigation** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$5,364** | **$158,402** |
| Materials | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $37,922 |
| Construction | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| Maintenance | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $5,364 | $107,280 |
| **Silviculture** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$143,164** |
| Fertilization | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $33,000 |
| Form control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $45,000 |
| Pest control | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $51,964 |
| Weed control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| **Harvesting** | **$21,864** | **$24,999** | **$27,753** | **$30,106** | **$32,074** | **$33,694** | **$35,010** | **$36,069** | **$36,916** | **$37,588** | **$379,105** |
| Overstory / ac | $1,874 | $2,188 | $2,463 | $2,699 | $2,895 | $3,057 | $3,189 | $3,295 | $3,380 | $3,447 | $32,918 |
| Transport, market / ac | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $4,992 |
| **Indirect costs** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$19,300** |
| Transport, machine | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $19,300 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $40,000 |
| **Management** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$113,050** |
| Establishment | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $4,750 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $38,000 |
| Silviculture | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,500 |
| Harvesting | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $60,800 |
| **Revenues** | **$77,295** | **$90,223** | **$101,581** | **$111,285** | **$119,401** | **$126,080** | **$131,507** | **$135,875** | **$139,366** | **$142,138** | **$1,357,478** |
| Overstory | $77,295 | $90,223 | $101,581 | $111,285 | $119,401 | $126,080 | $131,507 | $135,875 | $139,366 | $142,138 | $1,357,478 |
| Costs (direct) | -$34,128 | -$41,987 | -$40,017 | -$47,094 | -$44,338 | -$50,682 | -$47,274 | -$53,057 | -$49,180 | -$54,576 | **-$842,518** |
| Costs (indirect) | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | **-$19,300** |
| Revenues | $77,295 | $90,223 | $101,581 | $111,285 | $119,401 | $126,080 | $131,507 | $135,875 | $139,366 | $142,138 | **$1,357,478** |
| Annual net | $42,142 | $47,211 | $60,539 | $63,166 | $74,038 | $74,373 | $83,208 | $81,793 | $89,161 | $86,537 | **$495,660** |
| Annual gross margin | 55% | 52% | 60% | 57% | 62% | 59% | 63% | 60% | 64% | 61% | 37% |
| Summed net | -$164,364 | -$117,154 | -$56,615 | $6,551 | $80,589 | $154,962 | $238,169 | $319,962 | $409,123 | $495,660 | --- |

## *4.3.2.3. Jackfruit 1-10*

| Activity \| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$24,700** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Overstory / ac | $2,450 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Groundcover / ac | $20 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Establishment** | **$10,097** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Site preparation | $9,135 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Planting | $963 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Irrigation** | **$51,486** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** |
| Materials | $37,922 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Construction | $13,200 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Maintenance | $364 | $364 | $364 | $364 | $364 | $364 | $364 | $364 | $364 | $364 |
| **Silviculture** | **$4,500** | **$24,224** | **$24,224** | **$9,224** | **$16,200** | **$7,724** | **$3,000** | **$7,724** | **$3,000** | **$7,724** |
| Fertilization | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $3,000 | $3,000 | $3,000 | $3,000 | $3,000 |
| Form control | $0 | $15,000 | $15,000 | $0 | $15,000 | $0 | $0 | $0 | $0 | $0 |
| Pest control | $0 | $4,724 | $4,724 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 |
| Weed control | $3,300 | $3,300 | $3,300 | $3,300 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Harvesting** | **$0** | **$0** | **$0** | **$0** | **$6,734** | **$7,637** | **$8,767** | **$10,179** | **$11,943** | **$17,825** |
| Overstory / ac | $0 | $0 | $0 | $0 | $361 | $452 | $565 | $706 | $882 | $1,471 |
| Transport, market | $0 | $0 | $0 | $0 | $312 | $312 | $312 | $312 | $312 | $312 |
| **Indirect costs** | **$1,025** | **$625** | **$625** | **$625** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** |
| Transport, machine | $1,025 | $625 | $625 | $625 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| **Management** | **$8,550** | **$3,800** | **$3,800** | **$3,800** | **$5,700** | **$5,700** | **$5,700** | **$7,600** | **$5,700** | **$5,700** |
| Establishment | $4,750 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 |
| Silviculture | $1,900 | $1,900 | $1,900 | $1,900 | $0 | $0 | $0 | $1,900 | $0 | $0 |
| Harvesting | $0 | $0 | $0 | $0 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 |
| **Revenues** | **$0** | **$0** | **$0** | **$0** | **$10,551** | **$13,189** | **$16,486** | **$20,608** | **$25,760** | **$42,933** |
| Overstory | $0 | $0 | $0 | $0 | $10,551 | $13,189 | $16,486 | $20,608 | $25,760 | $42,933 |
| Costs (direct) | -$99,333 | -$28,388 | -$28,388 | -$13,388 | -$28,998 | -$21,425 | -$17,831 | -$25,866 | -$21,007 | -$31,613 |
| Costs (indirect) | -$1,025 | -$625 | -$625 | -$625 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 |
| Revenues | $0 | $0 | $0 | $0 | $10,551 | $13,189 | $16,486 | $20,608 | $25,760 | $42,933 |
| Net | -$100,358 | -$29,013 | -$29,013 | -$14,013 | -$19,472 | -$9,261 | -$2,369 | -$6,284 | $3,728 | $10,295 |
| Annual gross margin | --- | --- | --- | --- | -185% | -70% | -14% | -30% | 14% | 24% |
| Summed net | -$100,358 | -$129,371 | -$158,384 | -$172,397 | -$191,869 | -$201,130 | -$203,500 | -$209,783 | -$206,056 | -$195,761 |

## 4.3.2.4. Jackfruit 11-20

| Activity \| Year | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$24,700** |
| Overstory / ac | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $2,450 |
| Groundcover / ac | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $20 |
| **Establishment** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$10,097** |
| Site preparation | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,135 |
| Planting | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $963 |
| **Irrigation** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$364** | **$58,402** |
| Materials | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $37,922 |
| Construction | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| Maintenance | $364 | $364 | $364 | $364 | $364 | $364 | $364 | $364 | $364 | $364 | $7,280 |
| **Silviculture** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$143,164** |
| Fertilization | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $33,000 |
| Form control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $45,000 |
| Pest control | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $51,964 |
| Weed control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| **Harvesting** | **$27,629** | **$30,053** | **$32,716** | **$35,643** | **$38,860** | **$42,395** | **$46,279** | **$50,547** | **$55,238** | **$60,393** | **$482,838** |
| Overstory / ac | $2,451 | $2,693 | $2,960 | $3,252 | $3,574 | $3,927 | $4,316 | $4,743 | $5,212 | $5,727 | $43,292 |
| Transport, market | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $4,992 |
| **Indirect costs** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$19,300** |
| Transport, machine | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $19,300 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $40,000 |
| **Management** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$113,050** |
| Establishment | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $4,750 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $38,000 |
| Silviculture | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,500 |
| Harvesting | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $60,800 |
| **Revenues** | **$71,555** | **$78,632** | **$86,409** | **$94,955** | **$104,346** | **$114,666** | **$126,006** | **$138,469** | **$152,163** | **$167,213** | **$1,263,941** |
| Overstory | $71,555 | $78,632 | $86,409 | $94,955 | $104,346 | $114,666 | $126,006 | $138,469 | $152,163 | $167,213 | $1,263,941 |
| Costs (direct) | -$34,893 | -$42,041 | -$39,980 | -$47,631 | -$46,124 | -$54,383 | -$53,543 | -$62,535 | -$62,502 | -$72,381 | **-$832,251** |
| Costs (indirect) | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | **-$19,300** |
| Revenues | $71,555 | $78,632 | $86,409 | $94,955 | $104,346 | $114,666 | $126,006 | $138,469 | $152,163 | $167,213 | **$1,263,941** |
| Net | $35,638 | $35,567 | $45,404 | $46,298 | $57,197 | $59,258 | $71,438 | $74,908 | $88,636 | $93,807 | **$412,391** |
| Annual gross margin | 50% | 45% | 53% | 49% | 55% | 52% | 57% | 54% | 58% | 56% | **17%** |
| Summed net | -$160,123 | -$124,556 | -$79,153 | -$32,854 | $24,343 | $83,601 | $155,039 | $229,948 | $318,584 | $412,391 | --- |

### 4.3.3. Multi story agroforestry

#### *4.3.3.1. Cacao-Inga 1-10*

| Activity \| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$56,950** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Overstory / ac | $175 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Understory / ac | $5,500 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Groundcover / ac | $20 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Establishment** | **$25,197** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Site preparation | $10,485 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Planting | $14,713 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Irrigation** | **$71,858** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** |
| Materials | $48,094 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Construction | $13,200 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Maintenance | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 |
| **Silviculture** | **$5,700** | **$33,898** | **$33,898** | **$15,148** | **$21,150** | **$15,448** | **$6,000** | **$15,448** | **$6,000** | **$15,448** |
| Fertilization | $2,400 | $2,400 | $2,400 | $2,400 | $2,400 | $6,000 | $6,000 | $6,000 | $6,000 | $6,000 |
| Form control | $0 | $18,750 | $18,750 | $0 | $18,750 | $0 | $0 | $0 | $0 | $0 |
| Pest control | $0 | $9,448 | $9,448 | $9,448 | $0 | $9,448 | $0 | $9,448 | $0 | $9,448 |
| Weed control | $3,300 | $3,300 | $3,300 | $3,300 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Harvesting** | **$0** | **$0** | **$0** | **$0** | **$13,176** | **$26,483** | **$36,845** | **$40,990** | **$40,990** | **$41,113** |
| Overstory / ac | $0 | $0 | $0 | $0 | $31 | $61 | $123 | $147 | $147 | $159 |
| Understory / ac | $0 | $0 | $0 | $0 | $975 | $2,275 | $3,250 | $3,640 | $3,640 | $3,640 |
| Transport, market | $0 | $0 | $0 | $0 | $312 | $312 | $312 | $312 | $312 | $312 |
| **Indirect costs** | **$1,025** | **$625** | **$625** | **$625** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** |
| Transport, machine | $1,025 | $625 | $625 | $625 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| **Management** | **$8,550** | **$3,800** | **$3,800** | **$3,800** | **$5,700** | **$5,700** | **$5,700** | **$7,600** | **$5,700** | **$5,700** |
| Establishment | $4,750 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 |
| Silviculture | $1,900 | $1,900 | $1,900 | $1,900 | $0 | $0 | $0 | $1,900 | $0 | $0 |
| Harvesting | $0 | $0 | $0 | $0 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 |
| **Revenues** | **$0** | **$0** | **$0** | **$0** | **$28,750** | **$66,500** | **$97,000** | **$109,200** | **$109,200** | **$109,900** |
| Overstory | $0 | $0 | $0 | $0 | $1,750 | $3,500 | $7,000 | $8,400 | $8,400 | $9,100 |
| Understory | $0 | $0 | $0 | $0 | $27,000 | $63,000 | $90,000 | $100,800 | $100,800 | $100,800 |
| Costs (direct) | -$168,255 | -$48,262 | -$48,262 | -$29,512 | -$50,590 | -$58,194 | -$59,109 | -$74,602 | -$63,254 | -$72,824 |
| Costs (indirect) | -$1,025 | -$625 | -$625 | -$625 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 |
| Revenues | $0 | $0 | $0 | $0 | $28,750 | $66,500 | $97,000 | $109,200 | $109,200 | $109,900 |
| Net | -$169,280 | -$48,887 | -$48,887 | -$30,137 | -$22,865 | $7,281 | $36,866 | $33,573 | $44,921 | $36,051 |
| Annual gross margin | --- | --- | --- | --- | -80% | 11% | 38% | 31% | 41% | 33% |
| Summed net | -$169,280 | -$218,167 | -$267,054 | -$297,190 | -$320,056 | -$312,775 | -$275,909 | -$242,336 | -$197,415 | -$161,364 |

## *4.3.3.2. Cacao-Inga 11-20*

| Activity \| Year | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$56,950** |
| Overstory / ac | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $175 |
| Understory / ac | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $5,500 |
| Groundcover / ac | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $20 |
| **Establishment** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$25,197** |
| Site preparation | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $10,485 |
| Planting | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $14,713 |
| **Irrigation** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$10,564** | **$272,574** |
| Materials | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $48,094 |
| Construction | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| Maintenance | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $10,564 | $211,280 |
| **Silviculture** | **$2,400** | **$11,848** | **$2,400** | **$11,848** | **$2,400** | **$11,848** | **$2,400** | **$11,848** | **$2,400** | **$11,848** | **$239,377** |
| Fertilization | $2,400 | $2,400 | $2,400 | $2,400 | $2,400 | $2,400 | $2,400 | $2,400 | $2,400 | $2,400 | $66,000 |
| Form control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $56,250 |
| Pest control | $0 | $9,448 | $0 | $9,448 | $0 | $9,448 | $0 | $9,448 | $0 | $9,448 | $103,927 |
| Weed control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| **Harvesting** | **$41,113** | **$41,235** | **$41,358** | **$41,603** | **$41,848** | **$41,970** | **$41,970** | **$41,970** | **$41,970** | **$41,970** | **$616,601** |
| Overstory / ac | $159 | $172 | $184 | $208 | $233 | $245 | $245 | $245 | $245 | $245 | $2,848 |
| Understory / ac | $3,640 | $3,640 | $3,640 | $3,640 | $3,640 | $3,640 | $3,640 | $3,640 | $3,640 | $3,640 | $53,820 |
| Transport, market | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $4,992 |
| **Indirect costs** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$19,300** |
| Transport, machine | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $19,300 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $40,000 |
| **Management** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$113,050** |
| Establishment | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $4,750 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $38,000 |
| Silviculture | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,500 |
| Harvesting | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $60,800 |
| **Revenues** | **$109,900** | **$110,600** | **$111,300** | **$112,700** | **$114,100** | **$114,800** | **$114,800** | **$114,800** | **$114,800** | **$114,800** | **$1,653,150** |
| Overstory | $9,100 | $9,800 | $10,500 | $11,900 | $13,300 | $14,000 | $14,000 | $14,000 | $14,000 | $14,000 | $162,750 |
| Understory | $100,800 | $100,800 | $100,800 | $100,800 | $100,800 | $100,800 | $100,800 | $100,800 | $100,800 | $100,800 | $1,490,400 |
| Costs (direct) | -$59,777 | -$69,347 | -$60,022 | -$69,714 | -$60,512 | -$70,082 | -$60,634 | -$70,082 | -$60,634 | -$70,082 | **-$1,323,749** |
| Costs (indirect) | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | **-$19,300** |
| Revenues | $109,900 | $110,600 | $111,300 | $112,700 | $114,100 | $114,800 | $114,800 | $114,800 | $114,800 | $114,800 | **$1,653,150** |
| Net | $49,099 | $40,228 | $50,254 | $41,961 | $52,564 | $43,693 | $53,141 | $43,693 | $53,141 | $43,693 | **$310,101** |
| Annual gross margin | 45% | 36% | 45% | 37% | 46% | 38% | 46% | 38% | 46% | 38% | **31%** |
| Summed net | -$112,266 | -$72,038 | -$21,784 | $20,176 | $72,740 | $116,433 | $169,574 | $213,267 | $266,408 | $310,101 | --- |

## 4.3.4. Complex agroforestry

### *4.3.4.1. Cacao-jackfruit-Inga 1-10*

| Activity \| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$33,430** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Overstory | $9,250 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Understory | $23,980 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Windbreak / Groundcover | $200 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Establishment** | **$17,134** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** |
| Site preparation | $9,764 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Planting | $7,370 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Irrigation** | **$63,241** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** |
| Materials | $42,253 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Construction | $13,200 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Maintenance | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 |
| **Silviculture** | **$4,500** | **$24,224** | **$24,224** | **$9,224** | **$16,200** | **$7,724** | **$3,000** | **$7,724** | **$3,000** | **$7,724** |
| Fertilization | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $3,000 | $3,000 | $3,000 | $3,000 | $3,000 |
| Form control | $0 | $15,000 | $15,000 | $0 | $15,000 | $0 | $0 | $0 | $0 | $0 |
| Pest control | $0 | $4,724 | $4,724 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 |
| Weed control | $3,300 | $3,300 | $3,300 | $3,300 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Harvesting** | **$0** | **$0** | **$0** | **$0** | **$9,430** | **$15,996** | **$21,752** | **$24,465** | **$25,222** | **$27,743** |
| Overstory | $0 | $0 | $0 | $0 | $206 | $296 | $446 | $548 | $623 | $875 |
| Understory | $0 | $0 | $0 | $0 | $425 | $992 | $1,417 | $1,587 | $1,587 | $1,587 |
| Transport, market | $0 | $0 | $0 | $0 | $312 | $312 | $312 | $312 | $312 | $312 |
| **Indirect costs** | **$1,025** | **$625** | **$625** | **$625** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** |
| Transport, machine | $1,025 | $625 | $625 | $625 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| **Management** | **$8,550** | **$3,800** | **$3,800** | **$3,800** | **$5,700** | **$5,700** | **$5,700** | **$7,600** | **$5,700** | **$5,700** |
| Establishment | $4,750 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 |
| Silviculture | $1,900 | $1,900 | $1,900 | $1,900 | $0 | $0 | $0 | $1,900 | $0 | $0 |
| Harvesting | $0 | $0 | $0 | $0 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 |
| **Revenues** | **$0** | **$0** | **$0** | **$0** | **$18,044** | **$36,620** | **$53,306** | **$61,181** | **$63,389** | **$70,749** |
| Overstory | $0 | $0 | $0 | $0 | $6,272 | $9,152 | $14,066 | $17,232 | $19,440 | $26,800 |
| Understory | $0 | $0 | $0 | $0 | $11,772 | $27,468 | $39,240 | $43,949 | $43,949 | $43,949 |
| Costs (direct) | -$126,854 | -$35,811 | -$35,811 | -$20,811 | -$39,117 | -$37,207 | -$38,239 | -$47,577 | -$41,709 | -$48,954 |
| Costs (indirect) | -$1,025 | -$625 | -$625 | -$625 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 |
| Revenues | $0 | $0 | $0 | $0 | $18,044 | $36,620 | $53,306 | $61,181 | $63,389 | $70,749 |
| Net | -$127,879 | -$36,436 | -$36,436 | -$21,436 | -$22,098 | -$1,612 | $14,042 | $12,579 | $20,655 | $20,770 |
| Annual gross margin | 0% | 0% | 0% | 0% | -122% | -4% | 26% | 21% | 33% | 29% |
| Summed net | -$127,879 | -$164,315 | -$200,751 | -$222,188 | -$244,286 | -$245,898 | -$231,856 | -$219,277 | -$198,622 | -$177,852 |

## *4.3.4.2. Cacao-jackfruit-Inga 11-20*

| Activity \| Year | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Propagation** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$33,430** |
| Overstory | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,250 |
| Understory | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $23,980 |
| Windbreak / Groundcover | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $200 |
| **Establishment** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$17,134** |
| Site preparation | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,764 |
| Planting | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $7,370 |
| **Irrigation** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$7,787** | **$211,197** |
| Materials | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $42,253 |
| Construction | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| Maintenance | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $7,787 | $155,744 |
| **Silviculture** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$1,200** | **$5,924** | **$143,164** |
| Fertilization | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $1,200 | $33,000 |
| Form control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $45,000 |
| Pest control | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $0 | $4,724 | $51,964 |
| Weed control | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $13,200 |
| **Harvesting** | **$31,944** | **$32,983** | **$34,125** | **$35,379** | **$36,758** | **$38,272** | **$39,937** | **$41,766** | **$43,777** | **$45,986** | **$505,534** |
| Overstory | $1,295 | $1,399 | $1,513 | $1,639 | $1,777 | $1,928 | $2,095 | $2,278 | $2,479 | $2,700 | $22,096 |
| Understory | $1,587 | $1,587 | $1,587 | $1,587 | $1,587 | $1,587 | $1,587 | $1,587 | $1,587 | $1,587 | $23,466 |
| Transport, market | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $312 | $4,992 |
| **Indirect costs** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$1,025** | **$19,300** |
| Transport, machine | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $1,025 | $19,300 |
| Taxes and fees | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $40,000 |
| **Management** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$5,700** | **$113,050** |
| Establishment | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $4,750 |
| Irrigation | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $1,900 | $38,000 |
| Silviculture | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $9,500 |
| Harvesting | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $3,800 | $60,800 |
| **Revenues** | **$83,015** | **$86,048** | **$89,381** | **$93,044** | **$97,069** | **$101,491** | **$106,352** | **$111,693** | **$117,562** | **$124,011** | **$1,312,954** |
| Overstory | $39,067 | $42,099 | $45,432 | $49,095 | $53,120 | $57,543 | $62,403 | $67,744 | $73,613 | $80,063 | $663,139 |
| Understory | $43,949 | $43,949 | $43,949 | $43,949 | $43,949 | $43,949 | $43,949 | $43,949 | $43,949 | $43,949 | $649,814 |
| Costs (direct) | -$46,631 | -$52,394 | -$48,812 | -$54,790 | -$51,445 | -$57,684 | -$54,624 | -$61,178 | -$58,464 | -$65,397 | **-$1,023,509** |
| Costs (indirect) | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | -$1,025 | **-$19,300** |
| Revenues | $83,015 | $86,048 | $89,381 | $93,044 | $97,069 | $101,491 | $106,352 | $111,693 | $117,562 | $124,011 | **$1,312,954** |
| Net | $35,359 | $32,629 | $39,544 | $37,229 | $44,599 | $42,783 | $50,702 | $49,490 | $58,073 | $57,589 | **$270,145** |
| Annual gross margin | 43% | 38% | 44% | 40% | 46% | 42% | 48% | 44% | 49% | 46% | **21%** |
| Summed net | -$142,493 | -$109,864 | -$70,320 | -$33,091 | $11,508 | $54,291 | $104,993 | $154,483 | $212,555 | $270,145 | |

# 5. Planning and Implementation

Using general management prescriptions (§3) and core financial models (§4) supplemented by detailed silvicultural regimes for particular species (§1.4), the WFR agroforestry and timber projects would be implemented in two phases. The first phase (§5.1) would consist of numerous pilot projects established by interested community groups, NGO, academic agroforestry researchers, and contractors, all supported by nominal State and grant-based funding. These pilot projects would test an array of species combinations (§4) to identify assemblages and techniques that succeed in the unique biological and sociological environment of the WFR. The Phase I pilot projects, which will include fine-scale soil testing, site-species matching, and growth monitoring, will enable informed decisions concerning performance of and optimum locations for each species. The second phase (§5.2) would leverage results from the first to acquire additional funding and expand the acreage dedicated to agroforestry, timber, and promoting native Hawaiian species. By proposing to establish agroforestry systems, timber trees, and endemic species that are shown to thrive in the WFR, more certain project outcomes will lead to a greater likelihood of funding, whether from granting agencies or contractors. Four Phase II project levels (Tiers) are presented, each outlining the scale of projects possible with progressively greater funding.

## 5.1. Phase I

### 5.1.1. Pilot projects

Although similar agroforestry and timber projects exist across the tropics (Elevitch and Wilkinson, 2000), the WFR presents a unique set of challenges to overcome before agroforestry can succeed. The principal obstacles to project success include (1) insufficient knowledge of soil factors (nutrient availability, structure, erosion potential), (2) species-site matching, (3) implementation logistics (funding sources, detailed prescriptions), and (4) community interest, reaction, and involvement. These four obstacles are by no means insurmountable, but they must be approached at a small scale before there can be any likelihood of a favorable outcome for larger efforts. Some of the pilot project results will be clear soon after initiation, and can immediately be used to inform the Phase II projects. A probable timeline would see Phase I pilot projects initiated in the first year, with some projects sustained through at least five years (

Table 5.1.1). Some projects would yield results within two years, enabling selective Phase II expansion (

Table 5.1.1), while expanding the concepts behind more complex pilots would only be feasible after several years of experimentation and assessment.

| Activity | Year 1 | | | | Year 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| **Site preparation** | | | | | | | | |
| Overstory removal | ■ | | | | | | | |
| Digging (seedlings) | ■ | | | | | | | |
| **Establishment** | | | | | | | | |
| Planting | ■ | | | | | | | |
| Fertilizing | ■ | | | | | | | |
| Blanking | | ■ | | | | | | |
| **Maintenance** | | | | | | | | |
| Fertilizing | | | | | ■ | | | |
| Weed control | | | ■ | | ■ | | ■ | |
| Pest control | | ■ | | ■ | | ■ | | ■ |
| Form control | | | | | | | ■ | |

**Table 5.1.1. Pilot projects would be necessary to identify agroforestry systems and timber species most likely to succeed in the WFR. Project expansion could begin as early as the second year based on pilot study results.**

### 5.1.2. Soil sampling

Plants may tolerate a fairly wide range of abiotic (soil temperature, pH, structure, rainfall, irradiance) conditions, but they achieve maximum growth rates within a much narrower set of parameters. Soil factors, particularly pH, water content, and availability of certain critical nutrients, are among the most important determinants of plant growth , and it is inadvisable to establish a given species on substrate that has parameters known to be outside the optimal range. Some information is available about soils in the WFR (§1.2.3), but these data are generalized by soil type and identify only two different soils in the reserve. Tropical soils are known to be highly heterogeneous (Townsend *et al*. 2008) over very small spatial scale, particularly when topography is diverse, so it is likely that substantial variation in soil factors exists even within single WFR compartments. Before any agroforestry or timber species are established, a comprehensive soil survey should be conducted (§3.1). This study could be undertaken by the State of Hawaiʻi, by a contractor selected via the State RFP system, by graduate student(s) for whom such a project could be the foundation of a thesis, or even by qualified members of the Waimānalo community.

**Table 5.2**. **Budget for soil sampling pilot project**.

### 5.1.3. Species-site matching

Selecting species that perform well in each WFR compartment is a core objective for the pilot project phase. Several species-site matching (SSM) pilot studies will be necessary, and can be initiated only after soil test results are available; these should be used to develop a priority list of compartments whose nutrient, pH, water, and drainage profiles suitable for each species. This exercise may eliminate some of the species that are included in this FMP—should this occur, the species may be tested on a very limited basis (e.g. fewer than 10 plants rather than a replicated trial).

Three SSM trials are proposed for Phase I, each of which is intended to serve as a template for similar configurations during Phase II. Although the cost templates presented in this section refer to particular species (mahogany for timber, avocado for the single overstory fruit crop, cacao-Inga for combined agroforestry, Table 5.1.2), these costs would be essentially identical for any suite of species (Table 5.1.3). Each trial would be one acre or less in area, but reducing area at this scale does not lead to meaningful cost savings since the majority of expenditures for single acre models are management and indirect costs.

**Table 5.1.2. Cost estimates for single acre (or less-than-acre) pilot projects for several management case studies.**

| Average Net | Prescription | | |
|---|---|---|---|
| | SM | PA | TCIE |
| Year 1 $ac^{-1}$ | -$5,824 | -$13,822 | -$28,586 |
| Year 2-5 $ac^{-2}$ | -$570 | -$5,432 | -$6,250 |
| Year 6-10 $ac^{-3}$ | --- | -$5,550 | -$436 |
| Year 11-15 $ac^{-4}$ | --- | -$4,882 | $1,024 |
| Year 16-20 $ac^{-5}$ | --- | -$4,872 | $835 |
| Year 40 | $26,075 | --- | --- |
| **Total:** | **$19,682** | **-$112,073** | **-$46,470** |
| IRR 20 | 3.7% | | |
| NPV 20 $ac^{-1}$ | -$3,842 | -$81,961 | -$53,557 |

**The ultimate configuration of each Phase I trial will be determined by the land manager; configurations presented in this FMP serve as examples, and are not meant to be the definitive recommendation**. **The six most promising species in each category (Table 5.4) have been selected for the purpose of explaining how to implement these trials, but it is expected that other species would be added**. Each timber experiment would comprise one of the listed species, for six experiments in total. In contrast, each agroforestry experiment would comprise each of the six understory species planted with one overstory species, for a total of 36 experiments. Should the implementing manager add species, the number of experiments would increase in a multiplicative fashion (number overstory x number understory).

**Table 5.1.3. Phase I trials would include the most promising candidate species for timber plantings, single species fruit orchards, and more complex agroforestry configurations. Appropriate silvicultural prescriptions (§3) would need to be applied for each species; additional management time required to change prescriptions may increase costs.**

| Timber | Agroforestry | |
|---|---|---|
| | Overstory | Understory |
| *Cedrella odorata* | *Gliricidia sepium* | *Theobroma cacao* |
| *Elaeocarpus angustifolius* | *Inga edulis* | *Coffea arabica* |
| *Khaya senegalensis* | *Senna siamea* | *Coffea robusta* |
| *Sweitenia macrophylla* | *Artocarpus altilis* | *Annona squamosa* |
| *Thespesia populnea* | *Persea americana* | *Litchi chinensis* |
| *Santalum freycinetianum* | *Artocarpus heterophyllus* | *Pouteria sapota* |

Each SSM experiment should follow a standard design wherein eligible timber species or agroforestry species combinations are planted across the range of suitable compartments, as well as across the range of topography or other relevant gradients within each compartment. Capturing within-compartment variability is important because topography can strongly influence performance, either as an effect of slope position (e.g. Figure 3.3.3), drainage, fine-scale resource variation, or shading. In addition, pilot SSM should attempt to replicate plantings in a standard randomized block design. This approach is applicable for most scales, and a replicate may comprise only a few plants.

Plant performance (or plant compatibility in agroforestry trials) may be analyzed using at least two common statistical methods. To determine simply whether average growth or survival rates differ across compartments or resource gradients, the Analysis of Variance (ANOVA) technique  is appropriate. To construct predictive growth or survival models, a regression model testing framework  is necessary. These methods should be the basic tools for assessing SSM outcomes, but alternative (e.g. principal components analysis) or more sophisticated (e.g. Bayesian hierarchical models) techniques may be employed if those completing the analysis can reliably execute and interpret the procedures. To summarize, Phase II can be implemented based on ANOVA and regression results; alternate analyses may be useful from an academic perspective.

## 5.1.4. Site preparation

General prescriptions for site preparation (§3.3.1 - §3.3.3) were developed by analogy to similar sites and projects both in the literature  and in FSI experience. Likewise, the cost assessments (§4) were derived from comparable projects, common labor costs, work progress rates, and 2013 chemical price lists. Establishment experiments in Phase I will provide a crucial opportunity to ground-truth these cost assessments in an arena where project scale has minimal financial consequence. In the second phase, where project acreage could expand significantly, even slight inaccuracies in site preparation costs may be unacceptable.

## 5.1.5. Funding, logistics, and community

### *5.1.5.1. Funding*

Phase I soil testing, SSM experiments, and community involvement studies will reveal potential Phase II funding and logistics challenges. Funding the soil test may be accomplished by recruiting e.g. graduate students with parallel interests and their own funding and analytical support. This provides one model for certain Phase II projects, particularly the research and monitoring components. Some SSM studies may also follow this funding path. Alternate funding should be secured via grants, which may be submitted to the State of Hawaiʻi, to non-profits or NGO, to various federal agencies (LST), or to community development organizations (LST). Only limited funding is required for the several pilot projects (§5.2 - §5.4), and these small scale grants, though more likely to be funded, are practice sessions for securing larger awards. Successful Phase I grant applications also provide a template for Phase II proposals. While the current FMP provides cost assessments to a first approximation, site preparation and SSM studies will furnish more realistic values that can improve accuracy of Phase II financial models (§4).

### *5.1.5.2. Logistics and community*

The pilot projects, in addition to refining financial information, will highlight logistical problems and constraints that should be considered in Phase II proposals. Probable issues include (1) balancing agroforestry activities with recreational trail use, (2) developing efficient access to each compartment, (3) negotiating with community stakeholders, and (4) mitigating theft and vandalism.

1. Nā Ala Hele trail users will travel primarily on routes that do not coincide with agroforestry related paths. Where trail users encounter agroforestry will be at common ingress points and at two distinct intersections on the Ditch Trail. Activities in Phase I should lead to a good sampling of the types of probable interactions between these user groups as well as conflict resolution strategies.
2. Funding limitations in Phase I may allow only foot trail access to compartments for site preparation and planting. The logistical issues encountered in this process (efficient equipment transport, crew time management, safe transport of fragile seedlings) will improve methods and cost assessment for accessing remote compartments in Phase II timber or watershed projects.
3. Many of the operations in Phase I will simply occur at a larger scale in Phase II. Community interactions, either positive (Waimānalo residents participating in agroforestry projects and food distribution) or negative (trail users objecting to change, adjacent landowners suspicious of motive or disputing boundaries), in Phase I will establish precedent.
4. Theft of fruit crops and vandalism of agricultural infrastructure is unfortunately quite common in Hawaiʻi, and perhaps even more so in Waimānalo[10]. This project, being promoted by the State, implemented on State lands, and motivated by the public good, has the capacity to engage those who might otherwise commit destructive acts. Improving behavior in the commons will require public outreach and patient education efforts. Coercive measures (fencing, prohibitive signage) will never yield favorable results, would irreversibly cast the project in a negative light, and are thus strongly discouraged.

### *5.1.5.3. Community support*

Major elements of the Waimānalo community that may be interested in the DLNR DOFAW agroforestry include the Waimānalo Health Center[11] (WHC), the Waimānalo Agricultural Association (WAA), and the Waimānalo Neighborhood Board (WNB). Food education and distribution programs at WHC, including the federal Women, Infants, and Children (WIC) program, could be a local market for some produce, principally fruits, from the WFR. The WAA represents a network of farmers with substantial knowledge of local farming practices, which could (1) assist with selecting agroforestry systems that have a greater likelihood of success and community relevance, and (2) identify organizations, individuals, or contractors interested in implementing the prescriptions of this FMP. Likewise, the WNB represents wider interests of the Waimānalo community, including potential farmers, volunteer workers for watershed conservation projects, as well as recreational users of the WFR.

[10] Personal communication, Clifford Migita, Waimānalo Agriculture Association
[11] http://Waimānalohealth.org/

## 5.2. Phase II

During the development of any FMP, predicting funding levels, contractor capability, and community follow-through is inadvisable. Rather than constraining the FMP to any fixed trajectory, a more flexible approach will be enabled, outlining several possible paths appropriate for different degrees of funding availability and community interest. When future preparatory elements of the plan (e.g. environmental or archaeological assessments, §7) have clear outcomes, and when necessary results from Phase I pilot studies (§5.1) are available, the most appropriate trajectory for expansion can be selected. These paths are henceforth referred to as Tiers, where Tier 1 presents the lowest-intensity plan appropriate for small budgets or limited areas, and where Tier 4 presents a plan requiring the most aggressive funding, lack of constraints from the EA or AA, extensive community participation and effective State leadership. Total acreage available for each land use type (Figure) is a final uncertainty that cannot be resolved without the EA and a concurrence by the OCCL. Specifically, it is not possible to predict whether land currently designated Conservation District, subzone Resource will be usable for agroforestry or timber. Thus, plans at each Tier (§5.2.1 - §5.2.4) provide three zoning scenarios: (1) land use unchanged from 2013 (Current LUD), (2) allowing designated portions of the Conservation District to be reclassified and planted with timber species (RC Timber), and (3) allowing reclassification of Conservation District for agroforestry and timber (RC Ag, Timber).

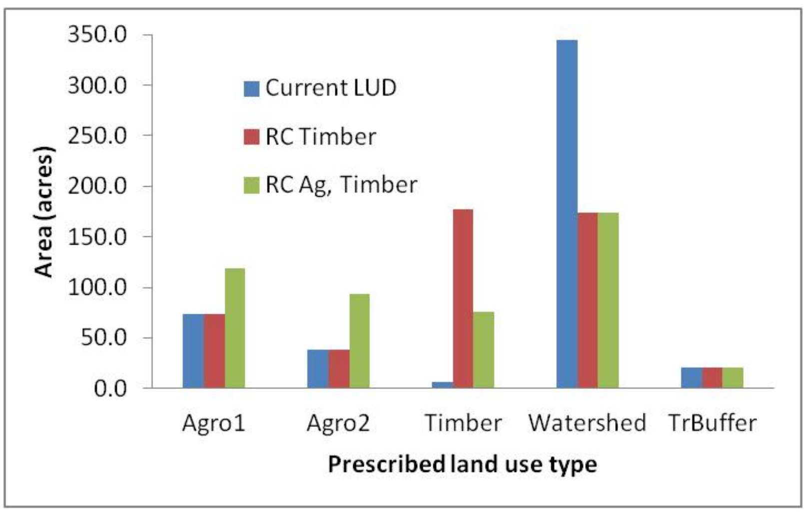



**Figure 5.2.1 Three scenarios for land use, including current LUD (left), timber planting allowed in the Conservation District (center), and both agroforestry and timber allowed in the Conservation District (right).**

The relative acreage devoted to each land use type typically increases from Tier 1 through Tier 4. For example, available timber land for e.g. mahogany plantings (Swma) would be 4% utilized in Tier 1, but 99% in Tier 4 (Table 5.2.1). The entity most appropriate for implementing each prescription within a plan depends on whether the majority investment must be financial or whether time may be substituted. For example, projects on larger acreages are feasible only with substantial initial investment, and are thus limited to execution by the State of Hawai'i DLNR DOFAW (State), contractors licensed by DLNR DOFAW, or NGO; Community groups, who are more likely to invest time rather than capital, are eligible for projects with smaller scope (Table 5.2.1). Economies of scale can be realized with larger acreage (Table 5.2.1), where the IRR can increase by several percent over the course of a rotation (Table 5.2.2) with increased investment. For example, limited acreage of jackfruit (abbreviated Arhe) yields 5.5% IRR, while larger acreage may yield 7.4% IRR (Table 4.2.5, Table 5.2.2). An IRR of 5.7% is likely for avocado (abbreviated Peam) plantings less than five acres; larger areas can achieve 7.7% IRR (


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Table 4.2.7, Table 5.2.2). The IRR for cacao planted with *Inga edulis* (abbreviated ThcaIned) or a combination if *I. edulis* and jackfruit (abbreviated ThcaInedArhe) is still reasonable (Table 5.2.2), but two or more separate silvicultural regimes increases project complexity and introduces some cost duplications (Table 5.2.2).

**Table 5.2.1. Prescriptions, executing entity, and percentage land use area dedicated to example management activities classified by FMC.**

| Working circle | Prescription | Execution | Example | Used available area (%) | | | |
|---|---|---|---|---|---|---|---|
| | | | | T1 | T2 | T3 | T4 |
| Timber | High value | State | Swma | 2 | 2 | 2 | 2 |
| | High value | Contractor | Swma | --- | 35 | 60 | 90 |
| | | | **Total %:** | **4** | **44** | **64** | **99** |
| Agroforest | Single tropical | State | Arhe | 1 | 5 | 7 | 8 |
| | Single tropical | Community | Peam | 1 | 5 | 7 | 20 |
| | Shade cacao | Contractor | ThcaIned | --- | --- | 10 | 12 |
| | Mixed cacao | Contractor | ThcaInedArhe | 1 | 10 | 15 | 15 |
| | | | **Total %:** | **7** | **39** | **63** | **99** |
| Watershed | Restoration | State | SocrAckoOsan | 2 | 2 | 2 | 2 |
| | Restoration | NGO | SocrAckoOsan | 0 | 0 | 5 | 10 |
| | | | **Total %:** | **2** | **2** | **7** | **12** |

Certain community supported prescriptions are exceptions to this trend of increasing returns with higher planted area. In particular, it is expected that community groups engaged in planting and maintenance would generally invest time rather than capital. Such groups would be most interested in agroforestry systems where the return (i.e. fruit) is realized in a short rotation. Thus, acreage of community supported agroforestry would increase from less than 1% of available agroforestry area in Tier 1 to more than 20% in Tier 4 (Table 5.2.1). By comparison, community groups may be somewhat less interested in timber planting, with perhaps a 45-year rotation and an unclear future market. Watershed plantings of native species, for example of māmane (*Sophora crysophylla*), koaia (*Acacia koaia*), and ulei (*Osteomeles anthyllidifolia*) (abbreviated SocrAckoOsan), have no traditional monetary incentive and may be implemented by persons or groups with a strong conservation ethic. Due to the lack of obvious return in the short term, these latter land use types are limited to just a few percent of the total available area regardless of the scale of the overall plan (Table 5.2.1).

**Table 5.2.2.** Rotation length varies from as few as 6 years for some fruit crops to more than 45 years for some timber species**. A range of IRR and NPV result from economies of scale regarding area-dependent aspects of establishment and project maintenance (low IRR and NPV result from smaller acreage; high IRR and NPV result from larger acreage). Net present value varies according to initial investment, with low values for timber projects and higher values for most agroforestry.**

| Working circle | Prescription | Execution | Example | Profitability | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Rotation (years) | IRR (low) | IRR (high) | NPV (low) | NPV (high) |
| Timber | High value | State | Swma | 45 | 7.9% | 8.1% | -$85 | $63 |
| | High value | Contractor | Swma | 45 | 7.9% | 8.1% | -$85 | $63 |
| Agroforest | Single tropical | State | Arhe | 11 | 5.5% | 7.4% | -$114 | $5,813 |
| | Single tropical | Community | Peam | 9 | 5.7% | 7.7% | -$5,268 | $2,703 |
| | Shade cacao | Contractor | ThcaIned | 6 | 5.1% | 5.9% | -$2,080 | $440 |
| | Mixed cacao | Contractor | ThcaInedArhe | 6 | 5.0% | 5.8% | -$2,015 | $441 |
| Watershed | Restoration | State | SocrAckoOsan | NA | NA | NA | NA | NA |
| | Restoration | NGO | SocrAckoOsan | NA | NA | NA | NA | NA |

### 5.2.1. Tier 1: $100,000 – $150,000

For minimal capital investment between $100,000 and $150,000, the assumptions underlying management prescriptions and financial models would allow establishment of up to 3.5 acres of timber, 3.2 acres of agroforestry, and 7.9 acres of watershed plantings (Table 5.2.3). The maximum acreage that can be planted within this price range would occur if the OCCL were to allow timber plantings in the Conservation District, but if agroforestry activities were disallowed. This constraint would maximize the area eligible for timber, which translates to greater planted area because of lower establishment costs. This level of funding is compatible with State and federal government grant proposals to supporting volunteer planting crews with limited DLNR DOFAW oversight. One possible distribution of management responsibility could delegate community groups, with State supervision, to plant timber and a simple overstory fruit orchard. Here, the overstory species is avocado (Table 5.2.3), but the model is applicable to any larger-stature fruit tree with similar silvicultural requirements such as ulu, jackfruit, soursop, mamey sapote, or lychee (Table 3.3.6). Community efforts would likely need to be augmented by State projects, for example additional overstory fruit plantings, demonstration dual-species systems, native species plantings in watershed compartments (Table 5.2.3). This level of funding is also compatible with grants from NGO, who could underwrite an acre of native species plantings in watershed compartments for a cost of approximately $5,000 (Table 5.2.3). Additional planting may be possible in the event that community groups are able to invest time in site preparation, with funding reserved for activities or purchases that are strictly monetary (purchase of seedlings and materials, fees for management).

**Table 5.2.3. Establishment funding requirements for Tier 1 forest management plan.**

| Working circle | Execution | Example | % | Area (acres) Current LUD | RC Timber | RC Ag, Timber | Cost to first net > 0 production Current LUD | RC Timber | RC Ag, Timber |
|---|---|---|---|---|---|---|---|---|---|
| Timber | State | Swma | 2 | 1.0 | 3.5 | 1.5 | $2,894 | $10,247 | $4,414 |
| | | Working Circle %: | 4 | 1.0 | 3.5 | 1.5 | $2,894 | $10,247 | $4,414 |
| Agroforest | State | Arhe | 1 | 1.0 | 1.0 | 1.0 | $20,686 | $20,686 | $20,686 |
| | Community | Peam | 1 | 1.0 | 1.0 | 1.0 | $27,313 | $27,313 | $27,313 |
| | Contractor | ThcaInedArhe | 1 | 1.0 | 1.0 | 1.2 | $24,478 | $24,478 | $29,121 |
| | | Working Circle %: | 7 | 3.0 | 3.0 | 3.2 | $72,477 | $72,477 | $77,120 |
| Watershed | State | SocrAckoOsan | 2 | 6.9 | 3.5 | 3.5 | $53,461 | $27,043 | $27,043 |
| | NGO | SocrAckoOsan | 0 | 1.0 | 1.0 | 1.0 | $5,217 | $5,217 | $5,217 |
| | | Working Circle %: | 2 | 7.9 | 4.5 | 4.5 | $58,678 | $32,260 | $32,260 |
| | | **Total:** | **---** | **11.9** | **11.0** | **9.2** | **$134,049** | **$114,984** | **$113,794** |

### 5.2.2. Tier 2: $300,000 – $650,000

A project of the Tier 2 spatial scale would be the first level at which the potential for profitability exists. Both large and small projects could be pursued. For example, State, federal, or non-profit grant funding could support community groups in the planting of timber on as many as 3.5 acres and fruit trees on as many as 4.7 acres (Table 1.2.1). Should the OCCL limit activities in the Conservation District to timber planting, this level of resources would allow State-funded timber plantings on 81 acres, with 11 acres of various agroforestry projects (Table 5.2.4). Projects could be established on a maximum acreage of 81 for $484,000 if strictly timber planting is allowed in the Conservation District (Table 5.2.4). If the OCCL allows both timber and agroforestry uses in the Conservation District, 54 acres could be planted for $610,000.

Profitable agroforestry could also be implemented on a contract basis, which could be achieve in two ways (§7.3). First, the State could be responsible for establishment and then cede maintenance and harvesting rights to a contractor in exchange for a fee to offset the costs of establishment (§7.3). Alternately, the State could release a request for proposals and accept the best proposal for a turn-key project; in this case, the licensed or permitted contractor would fund establishment and maintenance, with minimal fees assessed to offset administrative costs (§7.3).

**Table 5.2.4. Establishment funding requirements for Tier 2 forest management plan.**

| Working circle | Execution | Example | % | Area (acres) Current LUD | RC Timber | RC Ag, Timber | Cost to first net > 0 production Current LUD | RC Timber | RC Ag, Timber |
|---|---|---|---|---|---|---|---|---|---|
| Timber | State | Swma | 2 | 1.0 | 3.5 | 1.5 | $2,894 | $10,247 | $4,414 |
| | Contractor | Swma | 35 | 2.4 | 62.0 | 26.7 | $6,860 | $170,516 | $73,451 |
| | | Working Circle %: | 44 | 3.4 | 65.5 | 28.2 | $9,754 | $180,763 | $77,865 |
| Agroforest | State | Arhe | 5 | 1.9 | 1.9 | 4.7 | $39,195 | $39,195 | $96,379 |
| | Community | Peam | 5 | 1.9 | 1.9 | 4.7 | $51,751 | $51,751 | $116,041 |
| | Contractor | ThcaIned | --- | --- | --- | --- | --- | --- | --- |
| | Contractor | ThcaInedArhe | 10 | 7.3 | 7.3 | 11.9 | $179,869 | $179,869 | $287,520 |
| | | Working Circle %: | 39 | 11.1 | 11.1 | 21.2 | $270,814 | $270,814 | $499,939 |
| Watershed | State | SocrAckoOsan | 2 | 6.9 | 3.5 | 3.5 | $53,461 | $27,043 | $27,043 |
| | NGO | SocrAckoOsan | 0 | 1.0 | 1.0 | 1.0 | $5,217 | $5,217 | $5,217 |
| | | Working Circle %: | 2 | 7.9 | 4.5 | 4.5 | $58,678 | $32,260 | $32,260 |
| | | **Total:** | **---** | **22.4** | **81.1** | **53.9** | **$339,246** | **$483,837** | **$610,065** |

### 5.2.3. 5.2.3 Tier 3: $800,000 – $1,350,000

Greater funding support at Tier 3 would underwrite the expansion of contract-based projects. Community and NGO projects would continue at comparable levels to Tiers 1 and 2, but substantially greater acreage could be devoted to potentially profitable timber and agroforestry plantings (Table 5.2.5). With Conservation District allowing timber plantings, up to 146 acres could be planted at an establishment cost of $1 million (Table 5.2.5). Maximum agroforestry acreage of 43 could be established at a cost of $1.1 million, provided that agroforestry would be allowed in the Conservation District (Table 5.2.5).

**Table 5.2.5. Establishment funding requirements for Tier 3 forest management plan.**

| Working circle | Execution | Example | % | Area (acres): Current LUD | RC Timber | RC Ag, Timber | Cost to first net > 0 production: Current LUD | RC Timber | RC Ag, Timber |
|---|---|---|---|---|---|---|---|---|---|
| Timber | State | Swma | 2 | 1.0 | 3.5 | 1.5 | $2,894 | $10,247 | $4,414 |
| | Contractor | Swma | 60 | 4.1 | 106.2 | 45.8 | $11,760 | $292,313 | $125,916 |
| | | Working Circle %: | 64 | 5.1 | 109.8 | 47.3 | $14,654 | $302,560 | $130,330 |
| Agroforest | State | Arhe | 7 | 2.7 | 2.7 | 6.5 | $54,872 | $54,872 | $125,010 |
| | Community | Peam | 7 | 2.7 | 2.7 | 6.5 | $72,451 | $72,451 | $162,457 |
| | Contractor | ThcaIned | 10 | 7.3 | 7.3 | 11.9 | $236,163 | $236,163 | $377,994 |
| | Contractor | ThcaInedArhe | 15 | 11.0 | 11.0 | 17.8 | $266,386 | $266,386 | $431,280 |
| | | Working Circle %: | 63 | 23.7 | 23.7 | 42.8 | $629,873 | $629,873 | $1,096,740 |
| Watershed | State | SocrAckoOsan | 2 | 6.9 | 3.5 | 3.5 | $53,461 | $27,043 | $27,043 |
| | NGO | SocrAckoOsan | 5 | 17.2 | 8.7 | 8.7 | $133,652 | $67,609 | $67,609 |
| | | Working Circle %: | 7 | 24.1 | 12.2 | 12.2 | $187,112 | $94,652 | $94,652 |
| | | **Total:** | **---** | **52.9** | **145.6** | **102.3** | **$831,639** | **$1,027,085** | **$1,321,722** |

## 5.2.4. Tier 4: $1,100,000 – $1,900,000

With the lower bound of financing marginally exceeding the million dollar mark, a Tier 4 FMP could potentially establish high value forestry and agroforestry across 214 acres, or nearly 45% of the WFR (Table 5.2.6). This figure assumes timber plantings in the Conservation District; with agroforestry allowed in the CD, the higher cost of establishment would translate to plantings on 149 acres (Table 5.2.6).

**Table 5.2.6. Establishment funding requirements for Tier 4 forest management plan.**

| Working circle | Execution | Example | % | Area (acres): Current LUD | RC Timber | RC Ag, Timber | Cost to first net > 0 production: Current LUD | RC Timber | RC Ag, Timber |
|---|---|---|---|---|---|---|---|---|---|
| Timber | State | Swma | 2 | 1.0 | 3.5 | 1.5 | $2,894 | $10,247 | $4,414 |
| | Contractor | Swma | 90 | 6.1 | 159.3 | 68.6 | $17,640 | $438,470 | $188,874 |
| | | Working Circle %: | 99 | 7.1 | 162.9 | 70.2 | $20,534 | $448,716 | $193,288 |
| Agroforest | State | Arhe | 8 | 3.0 | 3.0 | 7.5 | $62,711 | $62,711 | $142,868 |
| | Community | Peam | 20 | 7.6 | 7.6 | 18.6 | $188,762 | $188,762 | $464,163 |
| | Contractor | ThcaIned | 12 | 8.8 | 8.8 | 14.3 | $280,168 | $280,168 | $453,593 |
| | Contractor | ThcaInedArhe | 15 | 11.0 | 11.0 | 17.8 | $266,386 | $266,386 | $431,280 |
| | | Working Circle %: | 99 | 30.5 | 30.5 | 58.2 | $798,027 | $798,027 | $1,491,903 |
| Watershed | State | SocrAckoOsan | 2 | 6.9 | 3.5 | 3.5 | $53,461 | $27,043 | $27,043 |
| | NGO | SocrAckoOsan | 10 | 34.5 | 17.4 | 17.4 | $267,303 | $135,217 | $135,217 |
| | | Working Circle %: | 12 | 41.3 | 20.9 | 20.9 | $320,764 | $162,260 | $162,260 |
| | | **Total:** | **---** | **78.9** | **214.2** | **149.3** | **$1,139,325** | **$1,409,004** | **$1,847,452** |

## 6. Research and Monitoring

Adaptive forest management relies on detailed planning and the capability to react when conditions change or outcomes differ from expectation. For the WFR agroforestry project, adaptive management would be achieved using a combination of vegetation monitoring and inventory (VMI) and permanent sampling plots (PSP). The former provides large-scale data at single time points pertaining to general ecosystem variables, while the latter constructs detailed, long term datasets designed to resolve particular research questions. The strategies are complementary, and both are necessary for a comprehensive record of project performance.

### 6.1. Species-site matching

Silvicultural prescriptions have been assigned to compartments based on a set of practical criteria, including slope, access, potential for irrigation, and remotely sensed vegetation cover, but additional refinements to these species-site combinations can be achieved once the project is under way. In particular, fine-scale soil nutrient and physical data can be combined with growth and survival data to optimize the spatial distribution of species among compartments in a given FMC.

The first phase of the project would be exploratory, with performance trials planted across the gradient of elevation, slope, and integrated soil fertility parameters (pH, eCEC) and set up using a complete randomized block design. For example, testing the relative performance of *C. odorata*, *E. angustifolius*, *S. macrophylla*, *E. microcorys*, and *T. populnea* requires a matrix of 25 blocks, where five blocks are reserved for each species and randomly distributed across the trial area (Figure 6.1.1). Typical geometry sets rows ten to 12 feet apart, with variable seedling spacing depending on tree shade tolerance, branching tendency, root zone requirements, and final stocking targets. A buffer zone of ten feet separates treatments or perimeter blocks to eliminate edge effects, for example additional light availability around the perimeter or interspecific competitive effects between blocks.

| | | | | |
|---|---|---|---|---|
| Ceod | Elan | Swma | Eumi | Thpo |
| Swma | Ceod | Eumi | Thpo | Elan |
| Thpo | Eumi | Elan | Swma | Ceod |
| Elan | Thpo | Eumi | Ceod | Swma |
| Ceod | Swma | Thpo | Elan | Eumi |

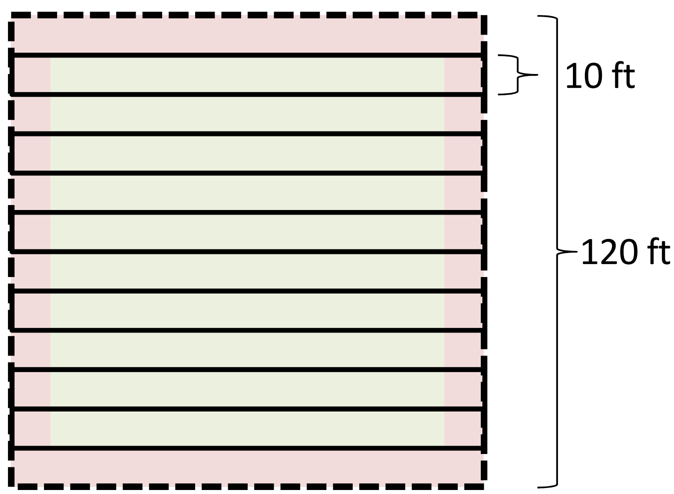


**Figure 6.1.1. Randomized block design for timber species performance trial. A complete design replicates each species to an equivalent degree and ensures that microsite conditions are minimally responsible for variation in performance by disaggregating blocks of a given species (left, species abbreviated as a concatenation of the first two letters of genus and species). Each block would consist of twelve rows spaced ten feet apart; the two edge rows and the last two seedlings at the end of every row would be excluded from census to maintain a buffer (red shading) of ten feet between treatments or edges (right).**

Seedling growth and survival would be measured at each trial through two years post-establishment. Growth would be assessed as height from the root collar to the tip of apical growth (not necessarily the highest leaf on the plant); when measurable, stem diameter at 4.5 ft above the ground would be added to the dataset. These growth variables are measured on a continuous scale, which lends them to analysis of variance (ANOVA), a standard statistical technique used to determine whether mean values differ across populations. During the first 18 months of Phase I (§5.1), applying ANOVA to height data, and potentially to diameter, should enable the selection of species best suited for the WFR. Timber, fruit trees, and native tree species that show statistically greater height growth in the first two years are most likely to continue growing faster than other species. Survival (assessed on a percent basis) should also affect species selection, and typically is positively correlated with growth rates. Notable exceptions to this tendency are often a consequence of poor establishment management, where e.g. competition control prescriptions are applied inconsistently causing fast-growing species to suffer from low survival rates.

### 6.2. Growth and yield

Whereas species-site matching identifies the best overall regime for each compartment, growth and yield analysis is necessary to forecast project performance and proactively alter management prescriptions to ensure that production objectives are met. Whether for timber or agroforestry, tree growth in the first few years can be extrapolated to later performance via several statistical techniques. Although a technical review is beyond the scope of this management plan, non-linear least squares regression is a standard method for selecting functions that describe tree growth over time (Burnham and Anderson 2002). Growth functions derived using this method for particular stands can then be compared against published or expected performance data to determine whether the WFR project will reach its goals. For timber plantings, growth and yield modeling means using tree diameter and height functions to predict ultimate timber yields. For agroforestry fruit or nut production, growth models (e.g. diameter) may be used in the early years as a proxy for fruit yield, while in later years yields should be measured directly and models derived specifically for output rather than tree size.

Growth and yield data should be collected using a combination of VMI and PSP methods, with differing approaches for timber and agroforestry. The core of each growth and yield model is the PSP network, which comprises plots that are measured repeatedly on a set schedule. After sufficient time, PSP data are capable of clearly defining growth curves. In comparison, VMI plots should be distributed across large areas, but should be measured only intermittently. Together, PSP and VMI provide adequate sampling of both temporal and spatial growth trends. Accurate growth trajectories derived from PSP data are then applied to VMI locations by adjusting the value of the function but retaining its general form.

For Phase II (§5.2) plantings, contractors or volunteers would take measurements of permanent sampling plots to project timber tree growth and survival rates. For compartments in which the selected timber species exhibits slow growth or excessive mortality, a financial assessment could be made whether to apply an alternate prescription. Likewise for agroforestry, measurement of tree growth as well as fruit production can identify under-performing compartments; these data can assist contractors to replace any failed crops with selections that will yield favorably.

## 6.3. Biodiversity and conservation

Biodiversity of native Hawaiian species in the WFR is highly constrained, limited to milo and ulei. Despite native Hawaiian biodiversity limitations, ecosystem services—principally erosion mitigation, but also maintenance of the aesthetic quality of closed-canopy forest—are well served by the community-level admixture. A chief management objective in watershed compartments is to improve representation and diversity of native Hawaiian plant species while also maintaining current ecosystem function and services. Because the primary method of watershed restoration will be outplanting by volunteer groups or NGOs, additional landscape-scale research will be necessary to determine whether these efforts are successful. This work, which could be completed by DOFAW staff, contractors, well-trained volunteers, or a combination of personnel, would assume the form of a standard vegetation cover survey, and would likely contrast community composition and structure in planted areas against analogous measurements in control compartments that do not receive restoration treatments.

# 7. Legal and administrative considerations

## 7.1. Prerequisite surveys

The WFR was designated as a Forest Reserve because of its critical role in stabilizing the steep slopes that surround Waimānalo Valley. The designation of the WFR as Conservation District dictates that any forest management activities conform to OCCL rules for Conservation Districts (**Appendix B**), although there may be provisions for reauthorization of certain currently prohibited activities (§7.2). Lifting some of the land use restrictions would require (1) and Environmental Assessment (EA) and (2) a Cultural and Archaeological Assessment (CAA). Should it be determined that the WFR does not contain critical habitats, endangered species, or cultural or archaeological features, the strong restrictions may be relaxed to allow the types of agroforestry and timber management detailed in this FMP. If some areas of the WFR do contain sensitive habitats or historical features, these portions may be declared off limits but some percentage of the area could nonetheless be eligible for forest management activities.

### 7.1.1. Environmental assessment

An indispensable element in the OCCL consultation process regarding whether agroforestry may be practiced in the WFR is an EA that conforms to State of Hawaiʻi Department of Health Title 11 Chapter 200 Rules (**Appendix F**). Requirements for the EA (Chapter 6 §11-200-10, **Appendix F**) include many of the components of the present FMP, from identifying the applicant agency (DLNR DOFAW), identifying groups consulted in completing the assessment, description of the management action, summary of effects (here, functionally equivalent ecosystems), agency determination, and consulting agencies. A list of all permits and approvals is also required, along with written comments following a 30-day public review of the EA document. Further Issues that should be addressed in the EA include (1) adequacy of proposed riparian buffers, (2) compatibility of agroforestry with Conservation District land that is subzone Resource, and (3) the potential for timber extraction either in the short term (e.g. removal of *F. moluccana* trees for canoe carving practice) or at the end of a high value hardwood rotation (e.g. selective uneven aged management for timber compartments).

### 7.1.2. Cultural and archaeological assessment

As with the EA, Hawaiʻi Administrative Rules govern land use in the presence of areas with cultural, historical, or archaeological significance (**Appendix G**). Before management actions may be undertaken, particularly in the Conservation District, it should be established that there are no historical features that may be adversely impacted. This may be achieved first using archival studies to determine whether a field assessment is necessary, and then pursuing the field component if required. A CAA may not be necessary for the entire WFR, particularly if the management actions proposed for a given compartment do not threaten historical or cultural features. In particular, watershed compartments and streamside management zones may not require a CAA.

## 7.2. Conservation district land use

Although beyond the scope of this FMP, submitting a standard Conservation District Use Application (CDUA, **Appendix I**) and receiving a Conservation District Use Permit (CDUP) should not be necessary for the WFR. Because both DOAFW and OCCL are at the same hierarchical level within the DLNR, a consultation process between the two divisions should be sufficient to establish broad operational guidelines for forestry activities in the WFR. **Conservation District rules presently operating in the WFR preclude many of the prescriptions in this FMP. The first step toward implementing this plan should be consultation with the OCCL to determine to what extent DOFAW may assume control of WFR management activities. A concurrence with OCCL under which DOFAW agrees to follow rules set for in HRS 343 (Appendix F).**

## 7.3. Land use permitting

This FMP has been written with a particular land ownership, administration, and project implementation structure. Specifically, the State of Hawai'i must retain ownership of every parcel because the land is a Forest Reserve. This ownership applies to compartments for all FMC, and precludes the possibility of land leases or licenses .

### 7.3.1. Timber

To establish high value hardwood timber on designated compartments, DLNR DOFAW would release a request for proposals (RFP) for turnkey contractor services. Contractors would submit proposals via the State of Hawai'i Electronic Procurement System (HePS), and the selected contractor(s) would be required to establish timber plantings on a set acreage. After the specified duration of the contract (24 months post-planting), the contractor would no longer be responsible for management, with responsibilities reverting to DLNR DOFAW. At that juncture, additional RFP could be released, for example to conduct monitoring and growth and yield modeling. The extended rotation required for timber production is fundamentally incompatible with contractor investment for the entire rotation.

### 7.3.2. Agroforestry

The relatively short timeframe required for agroforestry systems to begin production may justify, depending on the project scale, alternate forms of administration. State ownership remains a requirement, but contractor(s), NGO, and / or community organizations would respond to a series of RFP. Proposals would be solicited for maintenance of extant agroforestry orchards and for establishment of agroforestry projects. For the former, DLNR DOFAW could release RFP for turnkey project establishment services analogous to the timber plantings. Contractors would then complete this work, after which a second set of RFP would be released for project maintenance; this could be conducted either by the establishing contractor or by other groups, but would require a second proposal completed via the HePS submission process. Finally, DLNR DOFAW could establish agroforestry systems (either with internal funding and personnel or via an RFP) and then permit gathering or allow open access. Likely a combination of these administrative possibilities would be most effective.

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# 9. Abbreviations

| Abbreviation | Expansion |
|---|---|
| asl | above sea level |
| CAA | Cultural and Archaeological Assessment |
| CDUA | Conservation District Use Application |
| CDUP | Conservation District Use Permit |
| CTAHR | College of Tropical Agriculture and Human Resources |
| DLNR | Department of Land and Natural Resources |
| DOFAW | Division of Forestry and Wildlife |
| EA | Environmental Assessment |
| eCEC | effective Cation Exchange Capacity |
| FMC | Forest Management Class |
| FME | Forest Management Entity |
| FMP | Forest Management Plan |
| HePS | Hawaii electronic Procurement System |
| IRR | Internal Rate of Return |
| NGO | Nongovernmental Organization |
| NPV | Net Present Value |
| NRCS | Natural Resource Conservation Service |
| OCCL | Office of Conservation and Coastal Lands |
| PSP | Permanent Sample Plot |
| RFP | Request For Proposals |
| SOM | Soil Organic Matter |
| SSM | Species-Site Matching |
| TMK | Tax Map Key |
| USDA | United States Department of Agriculture |
| UTV | Utility Task Vehicle |
| VMI | Vegetation Monitoring and Inventory |
| WFR | Waimanalo Forest Reserve |

# 10. Appendices