ALA WAI CANAL ~~PROJECT~~ FLOOD RISK MANAGEMENT STUDY O'AHU, HAWAI'I

~~DRAFT~~FINAL FEASIBILITY STUDY REPORT WITH INTEGRATED ENVIRONMENTAL IMPACT STATEMENT

APPENDIX E
ENVIRONMENTAL AND REGULATORY COMPLIANCE

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Appendix E1
Summary of Federal and State Regulatory Compliance

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Federal and State Regulatory Compliance

Following is a discussion of the various regulations and policies that are applicable to the Ala Wai Canal Project, and the status of compliance with each regulation and policy.

Federal Regulations and Policies

National Environmental Policy Act

The National Environmental Policy Act (NEPA) establishes national environmental policy and goals for the protection, maintenance, and enhancement of the environment and provides a process for implementing these goals (42 United States Code [U.S.C.] 4321 *et seq*.). NEPA requires federal agencies to incorporate environmental considerations in their planning and decision-making process through a systematic interdisciplinary approach. Specifically, it requires full disclosure of the environmental effects, alternatives, potential mitigation, and environmental compliance procedures of the proposed action.

This draft Feasibility Study Report with integrated Environmental Impact Statement (EIS) has been prepared in compliance with NEPA and its implementing regulations (40 CFR Part 1500 through 1508). Pursuant to these regulations, the document describes the existing environmental conditions within the project site, the proposed action and alternatives, potential environmental impacts of the proposed project, and measures to minimize environmental impacts. Full compliance will be achieved when the Final EIS and Record of Decision (ROD) are filed with the EPA.

Clean Water Act

The purpose of the Clean Water Act (CWA; 33 U.S.C. 1251 *et seq*.) is to “restore and maintain the chemical, physical and biological integrity of the nation’s waters.” Section 404 of the CWA regulates the discharge of dredged or fill material into Waters of the U.S., which are defined to include rivers, streams, estuaries, the territorial seas, ponds, lakes, and wetlands; the USACE retains primary responsibility for this permit program (with oversight provided by EPA). USACE does not issue itself a permit under this program, but rather demonstrates compliance with the environmental criteria set forth in the Clean Water Act Section 404(b)(1) guidelines (40 CFR 230).[1] Section 404(b)(1) specifies that impacts to waters of the United States may only be permitted if there is no other practicable alternative that would have less adverse impact on the aquatic ecosystem and the action would not cause or contribute to significant degradation of the waters. As described in Section 5.4 of the Draft Feasibility Report/EIS, the project would result in discharge of fill material into Waters of the U.S. The Section 404(b)(1) evaluation for this project, which is contained in Appendix E, concludes that the proposed action is consistent with the specified guidelines, and that the tentatively selected plan is the least environmentally damaging alternative (LEDPA).

Under Section 401 of the CWA, applicants for a federal permit to conduct any activity that may result in a discharge of dredged or fill material to Waters of the U.S. must also obtain certification that any such discharge would comply with State water quality standards. The State of Hawai`i Department of Health

[1] If certain conditions are met, Clean Water Act Section 404(r) states that the discharge of dredged or fill material is not prohibited by or otherwise subject to regulation under Clean Water Act Section 404, Section 301(a), or Section 402 (except for effluent standards or prohibitions under Section 307). This applies only if information on the effects of such discharge, including consideration of the guidelines developed under Section 404(b)(1), is included in an EIS for such project pursuant to NEPA and such EIS has been submitted to Congress before (1) the actual discharge of dredged or fill material in connection with the construction of such project and (2) either authorization of such project or an appropriation of funds for each construction.

(DOH) administers the Section 401 water quality certification program, pursuant to HRS §342D, as discussed below.

Section 402 of the Clean Water Act regulates discharges of pollutants and stormwater to surface waters through the National Pollutant Discharge and Elimination System (NPDES) program; the program is administered by EPA, who has delegated oversight authority to the State of Hawaii DOH. The NPDES program is governed at the State level under HRS Chapter 342D, also discussed below.

Endangered Species Act

Section 7 of the Endangered Species Act (ESA; 16 U.S.C. 1536) prohibits Federal agencies from authorizing, funding, or carrying out activities that are likely to jeopardize the continued existence of a listed species or destroy or adversely modify its critical habitat. The USFWS is the administering agency for this authority regarding non-marine species. Through consultation with USFWS, agencies review their actions prior to implementation to determine if these could adversely affect listed species or their habitat.

In compliance with ESA consultation requirements, USACE requested information from USFWS regarding threated and endangered species and designated critical habitat within the overall Ala Wai watershed in April 2008. The USFWS responded in May 2008, and provided a list of federal listed species and designed critical habitat that could occur within the watershed. Follow-up meetings were held with agency staff on October 14, 2014; January 23, 2015; April 14, 2015; May 26, 2015; June 5, 2015; June 29, 2015; and July 29, 2015. The purpose of these meetings was to update agency staff on the current project status, discuss the project features, and to obtain any additional input on ESA-related issues.

Consultation was also initiated with NMFS in 2008; in response to USACE’s request, NMFS provided a complete list of ESA-listed species under their jurisdiction in the Hawaiian Archipelago on April 25, 2008. At the time of the original consultation, the project scope and objectives were more broadly defined, with the project area extending to include the nearshore marine waters. As the objectives and scope of the project were subsequently narrowed to focus on riverine-based flood risk management, the project is not expected to directly or indirectly affect the nearshore marine waters.

Based on this ongoing consultation, the USACE evaluated the potential impacts of the proposed project and summarized the results in a Draft Biological Assessment. As documented in the Draft Biological Assessment, USACE determined that the project may affect but is not likely to adversely affect the Hawaiian hoary bat, O‘ahu elepaio, and Hawaiian waterbirds (Hawaiian coot, Hawaiian stilt, and Hawaiian moorhen), with no effect on all other Federally listed/candidate species or designated critical habitat. As the blackline Hawaiian damselfly was initially thought to be restricted to higher elevations of the watershed (and therefore have no potential to occur within the project area), the Draft Biological Assessment included a no effect determination for this species. However, on July 28, 2015, USFWS identified blackline Hawaiian damselflies within the proposed footprint of the Waihi debris and detention basin (D. Polhemus, personal communication, July 29, 2015). Detailed information from USFWS regarding this species is still pending; however, USACE provided a letter to USFWS on August 5, 2015, with submittal of the Draft Biological Assessment, indicating USACE’s intention to initiate formal Section 7 consultation on the endangered blackline Hawaiian damselfly upon receipt of the species information.

A copy of the Draft Biological Assessment and ESA Section 7 correspondence is contained in Appendix E5; documentation of the completed Section 7 consultation process will be included in the Final Feasibility Report/EIS.

Migratory Bird Treaty Act

Native migratory birds of the United States are protected under the MBTA of 1918, as amended (16 U.S.C. 703-712 et. seq.); the list of birds protected under MBTA implementing regulations is provided at 50 CFR 10.13. This Act states that it is unlawful to pursue, hunt, take, capture or kill; attempt to take, capture or kill; possess, offer to or sell, barter, purchase, deliver or cause to be shipped, exported, imported, transported, carried or received any migratory bird, part, nest, egg or product. “Take” is defined as “to pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to pursue, hunt, shoot, wound, kill, trap, capture, or collect (16 U.S.C. 703-712).” Consistent with the analysis provided relative to the ESA, the project is not expected to adversely affect migratory species.

Magnuson-Stevens Fishery Conservation and Management Act

The 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1855(b)) establish provisions relative to Essential Fish Habitat (EFH), in order to identify and protect important habitats for federally managed marine and anadromous fish species. Federal agencies which fund, permit, or undertake activities that may adversely affect EFH are required to consult with the National Marine Fisheries Service (NMFS) regarding the potential effects of their actions on EFH, and respond to NMFS recommendations.

As described in the Draft Integrated Feasibility Report and Environmental Impact Statement (EIS), no portion of the project area has been designated as EFH, but the nearshore waters to which the streams and Canal drain (i.e. Mamala Bay) include EFH for various lifestages of bottomfish, pelagics, coral reef ecosystem, and crustaceans. An overview of the proposed project and a discussion of potential project-related impacts was the subject of a meeting with NMFS on June 29, 2015; based on this discussion and the analysis contained in the Draft Report, USACE has determined that there would be no adverse effect to EFH, such that consultation is not required.

Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act (FWCA) (16 U.S.C. 661) was established to provide for the protection of fish and wildlife as part of federal water resource development projects. It requires Federal agencies to coordinate with USFWS and State wildlife agencies during the planning of new projects or for modifications of existing projects so that wildlife conservation receives equal consideration with other features of such projects throughout the decision making process. Wildlife resources are conserved by minimizing adverse effects, compensating for wildlife resources losses, and enhancing wildlife resource values.

Coordination with USFWS and DLNR (including both the Division of Forestry and Wildlife (DOFAW) and Division of Aquatic Resources (DAR)) has been conducted under the FWCA throughout the planning process; specific meeting dates are summarized in Section 6.2 of the Draft Feasibility Report/EIS. Through this coordination, input has been requested from the agencies relative to the potential impacts to fish and wildlife species, and approaches to avoid, minimize and mitigate for those impacts (including compensatory mitigation). In addition to site visits to the proposed measure locations, discussions have included a detailed review of the proposed design drawings for both the flood risk management and the compensatory mitigation measures. Input received to date relates to: (1) consideration of potential impacts to Federally listed species and (2) consideration of water quality impacts due to flushing and mobilization of contaminants in multi-purpose detention basins. These considerations have been integrated into the planning process, as summarized throughout the Draft Feasibility Report/EIS. No high-risk issues or other significant concerns have been identified to date. A formal record of the agencies’ recommendations will be documented in a FWCA Section 2(b) Report, which will be included in the Final Feasibility Report/EIS.

National Historic Preservation Act

The National Historic Preservation Act (NHPA; 16 U.S.C. 470f), as amended, governs the preservation of cultural and historic resources. Specific to the proposed project, NHPA Section 106 requires Federal agencies to consider the effects of a proposed undertaking on properties that have been listed (or determined to be eligible for listing) in the National Register of Historic Places; properties that are listed (or are eligible for listing) in the National Register are referred to as "historic properties."

As described in 36 CFR Part 800.1, which are the implementing regulations for the historic preservation review process, the Section 106 process seeks to accommodate historic preservation concerns with the needs of federal undertakings through consultation. The goal of consultation is to obtain input as needed to identify historic properties potentially affected by the undertaking, assess the potential effects and seek ways to avoid, minimize or mitigate any adverse effects on historic properties. Consulting parties that should be involved in the Section 106 process include the State Historic Preservation Officer (SHPO), Native Hawaiian Organizations (NHOs), jurisdictional agency representatives, and other interested parties. Additionally, federal agencies must give the Advisory Council on Historic Preservation (ACHP) an opportunity to comment on the undertaking.

Section 106 compliance for projects for which no historic properties are identified within the area of potential effects (APE), or for which adverse effects are either not anticipated or are easily resolved, can typically be achieved through a standard consultation process. In certain circumstances, including projects for which the effects cannot be fully determined prior to approval of the undertaking, a memorandum of agreement (MOA) or a programmatic agreement may be executed to guide the resolution of adverse effects and mitigation. Such agreements are negotiated between the Federal agency, the SHPO, and possibly the ACHP; other individuals or entities, such as NHOs, may be invited to participate as consulting parties. In addition, the federal agency must make information available to the public, and provide an opportunity for public input.

In compliance with NHPA Section 106, consultation with the SHPO was initiated in a letter dated August 21, 2014. Ongoing consultation has been conducted with SHPO and other consulting parties, with input sought relative to definition of the APE, identification of historic properties within the APE, and determination of potential effects to those properties; a copy of the Section 106 consultation documents is contained in Appendix F. Consistent with the summary of impacts and mitigation described in the consultation documents, the USACE determined that there would be an adverse effect to historic properties. Treatment recommendations have been proposed to reduce many of the impacts to no adverse effect with conditions. In addition, a Programmatic Agreement is being developed to further identify resources, determine effects and establish the process for resolving adverse effects that may arise throughout the remaining planning, design, and construction phases of the project. This determination, with a request for concurrence, was provided to the SHPO and other consulting parties in a letter dated June 29, 2015; responses from SHPO and other consulting parties are pending. Responses received, as well as the Final Programmatic Agreement will be included as part of the Final Feasibility Report/EIS.

Coastal Zone Management Act

In response to the increasing pressure of development on coastal resources, the United States Congress enacted the Coastal Zone Management Act (16 U.S.C 1451-1464; CZMA) in 1972 and the Coastal Zone Act Reauthorization Amendments in 1990. These laws make federal financial assistance available to any coastal state or territory that is willing to develop and implement a comprehensive coastal management program. Hawai`i's CZM program was approved as HRS Chapter 205A in 1977; compliance with the various components of the State's program is further described below.

Clean Air Act

Clean Air Act, as amended, authorizes the EPA to establish NAAQS for major air pollutants. Based on measurements of ambient criteria pollutant data, EPA designates areas of the United States as having air quality equal to or better than NAAQS (attainment) or worse than NAAQS (non-attainment). The general conformity rule requires Federal agencies to ensure that actions they undertake in nonattainment and maintenance areas are consistent with air quality management plans for those areas. Because Hawaiʻi is, and always has been, in attainment for all pollutants, conformity analysis procedures do not apply to this project.

Air quality in the State of Hawai`i is delegated to the Clean Air Branch of DOH, and is governed at the State level under HRS §342B (Air Pollution Control); compliance with these requirements is further discussed below.

Uniform Relocation Assistance and Real Property Acquisition Policies Act

Federal, state, local government agencies, and others receiving Federal financial assistance for public programs and projects that require the acquisition of real property must comply with the policies and provisions set forth in the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, as amended in 1987 (42 USC 4601 et seq.), and implementing regulation, 49 C.F.R. Part 24. The act provides for relocation advisory services, moving costs reimbursement, replacement housing, and reimbursement for related expenses and rights of appeal.

While some land may need to be acquired to construct certain flood risk management measures, it is not anticipated that the project would require construction of new housing. However, if necessary, property acquisition and relocation services, compensation for living expenses for temporarily relocated residents, and negotiations regarding any compensation for temporary loss of business would be accomplished in accordance with this act.

Executive Orders

Executive Orders that are relevant to the proposed project and have been considered in the feasibility planning process include the following:

- **Executive Order 11514, Protection and Enhancement of Environmental Quality**: The objective of this executive order is to protect and enhance the quality of the Nation's environment to sustain and enrich human life. As summarized in this document, the potential effects of the project were assessed, in consultation with project stakeholders; compliance with all applicable environmental regulations is being obtained.
- **Executive Order 11988, Floodplain Management**: The objective of this executive order is to avoid, to the extent possible, long- and short-term adverse impacts associated with the occupancy and modification of the base floodplain, and avoid direct and indirect support of development in the base floodplain whenever there is a practicable alternative. Compliance with this executive order, based on the procedures outlined in ER 1165-2-26 (*Implementation of Executive Order 11988 on Flood Plain Management*; 30 March 1984), is discussed in Section 8.6 of the Draft Feasibility Report/EIS.
- **Executive Order 11990, Protection of Wetlands**: The objective of this executive order is to minimize the loss or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands. As discussed in Section 5.7 of the Draft Report, some small pockets of wetlands may exist within the limits of the channels, but no adjacent wetland features have been identified. Impacts to aquatic habitat within the stream channels will be mitigated so as to achieve no net loss of habitat function.

- **Executive Order 12898, Environmental Justice**: The objective of this executive order is to make it a high priority to identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of programs, policies and activities on minority and low-income populations. As discussed in Section 5.18 of the Draft Feasibility Report/EIS, the project alternatives are not expected to have a disproportionate effect on minority or low-income populations in the project area.
- **Executive Order 13045, Protection of Children From Environmental Health Risks and Safety Risks**: The objective of this executive order is to make it a high priority to identify and assess environmental health risks and safety risks that may disproportionately affect children. As discussed in Section 5.18 of the Draft Feasibility Report/EIS, the project is not expected to involve risks that would disproportionately affect children.
- **Executive Order 13112, Invasive Species**: The objective of this executive order is to prevent the introduction of invasive species, provide restoration of native species and habitat conditions in ecosystems that have been invaded, and promote public education and the means to address invasive species. The proposed project would include BMPs intended to address the introduction or spread of invasive species, and would incorporate native species as part of revegetation and mitigation efforts, where practicable.

State Regulations and Policies

Hawaii Environmental Impact Review Law (HRS Chapter 343)

HRS Chapter 343 is designed to “establish a system of environmental review which will ensure that environmental concerns are given appropriate consideration in decision making along with economic and technical considerations.” The regulations identify nine specific activities that trigger the need for compliance. The proposed action involves multiple activities that are triggers for compliance with HRS Chapter 343: (1) use of State or County lands or funds, (2) use within any land classified as Conservation District, (3) use within any historic site as designated in the National Register or Hawai`i Register, and (4) use within the Waikiki area. This Draft Feasibility Report/EIS has been prepared in compliance with HRS Chapter 343; DLNR is the proposing agency and the Governor will be the accepting authority. Full compliance will be achieved when the Final EIS is accepted by the Governor.

Hawaii State Environmental Policy (HRS Chapter 344)

The purpose of HRS Chapter 344 is to “establish a State policy which will encourage productive and enjoyable harmony between people and their environment, promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of humanity, and enrich the understanding of the ecological systems and natural resources important to the people of Hawai`i.” It specifies that the programs, authorities, and resources of the State be used to conserve natural resources and improve the quality of life. Particular aspects of the policy that relate to the project includes a focus on encouraging “productive and enjoyable harmony between people and their environment” and “the health and welfare of humanity.” Consistent with the policy and guidelines, the project seeks to balance protection of the environment and quality of life through protection against flood risks.

Coastal Zone Management (HRS Chapter 205A)

In response to the federal CZMA (16 U.S.C. §1451-1456), Hawai`i’s CZM program was enacted as HRS Chapter 205A in 1977, and is administered by the State of Hawai`i Department of Business, Economic Development and Tourism (DBEDT) Office of Planning. The CZM area encompasses the entire state, including all marine waters seaward to the extent of the State’s police power and management authority, including the 12-mile U.S. territorial sea and all archipelagic waters. The Hawai`i CZM program integrates decisions made by state and county agencies such as the Land Use Commission, DLNR, DOH, Department of Transportation, and Department of Agriculture to provide greater coordination and compliance with existing laws and rules. Specifically, the program focuses on ten policy objectives:

- Recreational Resources
- Historic Resources
- Scenic and Open Space Resources
- Coastal Ecosystems
- Economic Uses
- Coastal Hazards
- Managing Development
- Public Participation
- Beach Protection
- Marine Resources

Key components of Hawaii's CZM program include (1) regulation of development within the SMA, a designated area extending inland from the shoreline, (2) a Shoreline Setback Area, which serves as a buffer against coastal hazards and erosion, and protects view planes, and (3) a Federal Consistency provision, which requires that federal activities, permits, and financial assistance be consistent with the Hawai`i CZM program. The project would not involve any work within the Shoreline Setback Area or SMA. In compliance with the Federal Consistency provision, the USACE evaluated the proposed project for consistency with the policies of the Hawai`i CZM program. Based on this evaluation, the project was found to be consistent to the maximum extent practicable with the State coastal zone management program; the USACE's Federal Consistency determination was submitted to the Office of Planning for their certification on August 5, 2015 (see Appendix E4). Documentation of concurrence will be included in the Final Report.

Conservation District (HRS Chapter 183C)

The Conservation District was created to protect important natural resources essential to the preservation of the state's fragile natural ecosystems and the sustainability of the State's water supply. Land uses within the Conservation District are under the sole jurisdiction of the State and are governed by HRS Chapter 183C and HAR §13-5. The Conservation District is divided into five subzones: protective, limited, resource, and general, and a "special" subzone to accommodate unique projects (HRS §183C-1).

The DLNR Office of Conservation and Coastal Lands (OCCL) is responsible for regulating land uses within the Conservation District, in accordance with HAR §13-5-22. The project would involve work within the Conservation District at several of the measure locations in the upper portions of the watershed. A Conservation District Use Permit would be obtained from OCCL prior to construction.

Forest Reserve (HRS Chapter 183)

The State's Forest Reserve System was created by the Territorial Government of Hawai'i through Act 44 in 1903. It is managed by the State DLNR Division of Forestry and Wildlife (DOFAW) under HRS Chapter 183, and implementing rules (HAR Section 104). Through these directives, DOFAW focuses on protection, management, restoration, and monitoring of natural resources in the State's Forest Reserves. The proposed project would involve work within the Honolulu Watershed Forest Reserve. Consistent with the requirements of HAR Section 104, it is expected that a Forest Reserve Special Use Permit would be required; this permit would be obtained prior to construction.

State Water Code (HRS Chapter 174C)

HRS Chapter 174C, the State Water Code, was enacted into law by the 1987 Hawai`i State Legislature for the purpose of establishing a comprehensive water resource planning program to protect Hawai`i's water resources. It is intended to obtain maximum beneficial use of the waters of the State, while providing for protection of traditional and customary Hawaiian rights, protection and procreation of fish and wildlife, and other uses in the public interest.

As specified in the implementing rules (HAR Section 169), a Stream Channel Alteration Permit is required for any temporary or permanent activity within the stream bed or banks that may: 1) obstruct, diminish, destroy, modify, or relocate a stream channel; 2) change the direction of the flow of water in a stream channel; or 3) remove any material or structure from a stream channel. Routine streambed and drainageway maintenance activities and the repair of existing facilities are generally exempt from the SCAP requirements. As the project will involve channel alterations for construction of some of the measures, a SCAP will be obtained from CWRM prior to construction.

Conservation of Aquatic Life, Wildlife and Land Plants (HRS Chapter 195D)

HRS §195D, administered by DLNR, prohibits any taking, transport or commerce of aquatic, wildlife, or plant species deemed to be in need of conservation. It adopts the status of all species listed as threatened or endangered under the ESA, and allows further designation of additional species. For actions that may result in take of a State listed species, an incidental take license may be obtained as part of a habitat conservation plan, which includes consultation with the Endangered Species Recovery Committee. As described relative to the ESA, the USACE has determined that the project is not likely to adversely affect threatened or endangered species. The non-Federal sponsor is responsible for confirming compliance with HRS Chapter 195D.

Historic Preservation (HRS Chapter 6E)

HRS Chapter 6E establishes a comprehensive historic preservation program that is intended to preserve, restore and maintain historic and cultural properties. The regulations are implemented by SHPD, and require review of any project that is funded or permitted by the State. This process is the State counterpart to the Section 106 consultation requirement to identify historic properties potentially affected by a proposed project and can be an additional avenue of information gathering for fulfilling the Section 106 consultation mandate.

Specifically, HRS Chapter 6E (§6E-8 and §6E-42) requires that: "Before any agency or officer of the State or its political subdivisions commences any project which may affect historic property, aviation artifact, or a burial site, the agency or officer shall advise the department and allow the department an opportunity for review of the effect of the proposed project on historic properties, aviation artifacts, or burial sites, consistent with Chapter 6E-43, especially those listed on the Hawai`i register of historic places. The proposed project shall not be commenced, or in the event it has already begun, continued, until the department shall have given its written concurrence." HRS Chapter 6E-43 governs burial sites, and gives authority to the appropriate island burial council relative to treatment of burial sites.

The implementing rules for the historic property review process are contained in HAR Chapter 13-275; these rules apply to "all state or county agencies funding or directly undertaking a project, or having a project undertaken on lands under its ownership or control which may affect historic properties" (§13-275-1b). They address the specific requirements relative to conducting archaeological, ethnographic and/or architectural inventory surveys. Consistent with these requirements, HRS Chapter 343 includes a requirement to consider cultural practices as part of an environmental review of the effects of a proposed action; a cultural impact assessment has been completed in compliance with this requirement (see Appendix F2).

Project information, including archaeological studies and the cultural impact assessment have been provided to SHPD, in conjunction with the NHPA Section 106 process. The non-Federal sponsor is responsible for completing any requirements in compliance with HRS Chapter 6E.

Air Pollution Control (HRS Chapter 342B)

Air quality in the State of Hawai`i is regulated by the Clean Air Branch of DOH, as authorized under HRS §342B (Air Pollution Control). HAR Title 11, Chapter 59 (Ambient Air Quality Standards) establishes State ambient air quality standards, which in some cases are more stringent than the comparable Federal standards or address pollutants that are not covered by the Federal standards established under the Clean Air Act. These standards are monitored and enforced by the Clean Air Branch.

The implementing rules relating to air pollution control are set forth in HAR Section Chapter 60. Under these rules, an Air Pollution Control Permit is required before constructing, reconstructing, modifying, or operating a stationary air pollution source. Certain air pollution sources are exempt from these requirements including vehicles, trucks, cranes, graders, and loaders (HAR §11-60.1-62d). Stationary sources with potential emissions of less than 1.0 ton per year for each air pollutant are also exempt from Air Pollution Control Permit requirements. Because of the type of equipment anticipated for use during construction and operation of the project, and the low levels of emissions anticipated as described in Section 5.13 of the Draft Report, the project is not expected to require an Air Pollution Control Permit from the Clean Air Branch.

Water Pollution (HRS Chapter 342D)

The authority to administer both CWA Section 401 and Section 402 have been delegated to the State of Hawaii. The Department of Health (DOH) implements the State's Water Quality Certification Program and National Pollution Discharge Elimination System (NPDES) program, respectively, under HRS Chapter 342D.

As required by CWA Section 401, the objective of the Water Quality Certification Program is to ensure that any federally permitted activity will not adversely impact the existing uses, designated uses, and applicable water quality criteria of the receiving State waters. These requirements are based on the implementing rules contained in HAR 11-54. A Section 401 water quality certification will be obtained from the DOH prior to construction.[2]

Consistent with the requirements of CWA Section 402, Hawai`i's NPDES program regulates point source pollutant discharges and storm water. The implementing rules of the program are contained in HAR 11-55. Specifically, HAR 11-55-04 states that "before discharging any pollutant, or beginning construction activities that disturb one or more acres of land, or substantially altering the quality of any discharges, or substantially increasing the quantity of any discharges, a person shall submit a complete NDPES permit application…, submit a complete notice of intent…, or for certain storm water discharges, meet all requirements for a conditional "no exposure" exclusion." Issuance of an NPDES permit typically requires development and implementation of a Stormwater Pollution Prevention Plan (SWPPP), which should include measures to avoid or minimize adverse effects of sediment, erosion, and pollutants on surface waters. The specific requirements for the project will be determined in coordination with DOH and the permit will be obtained prior to construction.

[2] Prior to issuance of the Final Feasibility Report/EIS, USACE will seek reasonable assurance from DOH that Water Quality Certification can be obtained for this project.

Noise Pollution (HRS Chapter 342F)

The Noise Control Act of 1972, along with its subsequent amendments (Quiet Communities Act of 1978 [42 U.S.C. Parts 4901-4918]), delegates the authority to regulate environmental noise to each state. For Hawai`i, regulations to prevent, control, and abate noise pollution are set forth in HRS Chapter 342F. The implementing rules, which include statewide noise standards, are provided in HAR §11-46 ("Community Noise Control"); these are administered by HDOH. The stated purpose of the standards is to "provide for the prevention, control, and abatement of noise pollution in the State from the following noise sources: stationary noise sources (such as air-conditioning units, exhaust systems, generators, compressors, and pumps); and equipment related to agricultural, construction, and industrial activities" (HAR §11-46). The noise standards are the maximum permissible sound levels (as measured from the property line) and vary according to land use district. It is anticipated that noise levels during construction could exceed the maximum permissible sound levels; pursuant to HAR §11-46-7, a permit would be obtained from HDOH, as needed.

Appendix E2

~~Draft~~Final Mitigation and Monitoring Plan

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Final

Mitigation, Monitoring and Adaptive Management Plan

Ala Wai Canal Project; Oahu, Hawaii

U.S. Army Corps of Engineers, Honolulu District

August ~~2015~~2016

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7 Addendum to Mitigation, Monitoring, and Adaptive Management Plan, and Report on Updating the Spreadsheet Results for the HSHEP, July 2016

1.0 Introduction

At the request of the State of Hawaii Department of Land and Natural Resources (DLNR) and as authorized under Section 209 of the Flood Control Act of 1962, the U.S. Army Corps of Engineers, Honolulu District (USACE) is conducting a feasibility study for the Ala Wai Canal Project, Oahu, Hawaii[1] (hereafter referred to as “the project”). The purpose of the project is to reduce the threat to life and reduce property damage from riverine flooding within the Ala Wai Watershed.

The Ala Wai Watershed is located on the southeastern side of the island of Oahu, Hawaii. The watershed encompasses 19 square miles (mi^2) (12,064 acres) and extends from the ridge of the Ko`olau Mountains to the nearshore waters of Mamala Bay. It includes Maikiki, Manoa, and Palolo Streams, which drain to the Ala Wai Canal, a 2-mile-long, man-made waterway constructed during the 1920s to drain extensive coastal wetlands. This construction and subsequent draining allowed the development of the Waikiki district.

The project is currently a feasibility study, considering a variety of non-structural and structural flood risk management measures. Plan formulation and evaluation resulted in tentative selection of an alternative plan for implementation (referred to as the tentatively selected plan). A detailed discussion of the plan formulation process and the components of the tentatively selected plan are provided in the Draft Feasibility Study Report with Integrated Environmental Impact Statement (EIS), hereafter referred to as “Feasibility Report/EIS.”

As detailed in the Implementation Guidance for Section 2036(a) of the Water Resources Development Act (WRDA) of 2007– Mitigation for Fish and Wildlife and Wetland Losses, it is the policy of the USACE Civil Works program to demonstrate that damages to all significant ecological resources have been avoided and minimized to the extent practicable, and that any remaining unavoidable damages have been compensated to the extent possible. The mitigation planning process should seek to compensate for non-negligible impacts to the extent incrementally justified and ensure that the recommended project will not have more than negligible adverse impacts on ecological resources. Engineering Regulation (ER) 1105-2-100 (“Planning Guidance Notebook”) requires the use of a habitat-based methodology, supplemented with other appropriate information to describe and evaluate the impacts of the alternatives plans, and to identify the mitigation need of the with-project condition as measured against the future without-project condition. Once a mitigation need has been identified, mitigation objectives must be developed to address the identified losses. Mitigation objectives are used to guide formulation of appropriate mitigation management features and to establish benchmarks for evaluating the performance of the mitigation plans.

The regulations require assessment of environmental impacts and associated mitigation actions in a manner that addresses changes in ecological resource quality. Changes to habitat must be assessed as a function of improvement or degradation in habitat quality and/or quantity, as expressed quantitatively in physical units or indexes (but not monetary units). In the case of mitigation for significant environmental impacts, ecosystem restoration actions must be formulated and evaluated in terms of their net contributions to increases in ecosystem value, expressed in non-monetary units. Mitigation actions also need to go through a Cost Effectiveness and Incremental Cost Analysis (CE/ICA) to ensure benefits are optimized relative to cost.

Preparation of a mitigation plan is required, and should present the objectives, plan design, determination of success criteria and monitoring needs, all of which should be developed in

[1] The project has also previously been referred to as the “Ala Wai Watershed Project”; for consistency with the Congressional documentation, the project will continue to be referred to as the “Ala Wai Canal Project.”

coordination with Federal and State resource agencies to the extent practicable. The mitigation plan should include the following:

(1) a description of the physical action to be undertaken to achieve the mitigation objectives within the watershed in which such losses occur;

(2) the type, amount, and characteristics of the habitat being restored;

(3) ecological success criteria for mitigation based on replacement of lost functions and values of the habitat, including hydrologic and vegetative characteristics;

(4) a plan for monitoring to determine the success of the mitigation, including the cost and duration of any monitoring and the entities responsible for any monitoring;

(5) a contingency plan (i.e. adaptive management) for taking corrective actions in cases where monitoring demonstrates that mitigation measures are not achieving ecological success; and

(6) should land acquisition be proposed as part of the mitigation plan, a description of the lands or interests in lands to be acquired for mitigation and the basis for a determination that such lands are available for acquisition.

This mitigation and monitoring plan has been developed in compliance with these requirements. It includes a discussion of the quantification of habitat impacts, identification of mitigation objectives and proposed mitigation actions, and development of the proposed monitoring and adaptive management approach.

2.0 Assessment of Impacts to Aquatic Habitat

As described above, USACE regulations require the use of a habitat-based methodology to describe and evaluate the impacts of alternative plans, as well as to identify the need for mitigation to offset unavoidable ecological impacts of the with-project conditions as measured against the future without-project condition. As the outputs of ecosystem restoration are not readily convertible to actual monetary units (as is required for traditional benefit-cost analyses), ecosystem outputs must be clearly identified and quantified in appropriate units, preferably ones that measure change in ecosystem value and productivity. Measurable changes in ecosystem values are typically described in terms of suitability indices or habitat units, with an ecosystem output model used to quantify the changes over a 50-year period of analysis. Following is a description of the ecosystem output model selected for use on the project, and a summary of the modeling results for the existing (without-project) condition and with implementation of the tentatively selected plan.

2.1 Description of Ecosystem Model

Analogous with Habitat Evaluation Procedure (HEP) method and Habitat Suitability Index models developed by natural resource biologists elsewhere, the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) is a habitat-based model that was developed as a tool to support management of Hawaii's streams and associated habitat for freshwater flora and fauna. Specifically, the model is intended to provide managers with the ability to quantify changes in habitat for native Hawaiian stream animals in response to actions such as channel alterations, flow modifications, land use change and watershed development, or construction of in-channel structures. It captures the major aspects of native stream animal ecology, the typical geomorphology of Hawaiian streams, and common modifications to the environment.

The HSHEP model is an outgrowth of a history of collaboration among biologists at the State of Hawaii Division of Aquatic Resources (DAR) and researchers at various universities, agencies, museums, and private companies. The collaborative effort focused on understanding the different aspects of the ecology and management of amphidromous stream animals, which have a life history involving downstream and upstream migration (Fitzsimons and Nishimoto, 2007). In recent years, efforts have focused on combining the information gained from the wide range of studies into an integrated model of Hawaiian streams that include the life history characteristics of amphidromous animals, island hydrology and geomorphology, and critical management issues.

The HSHEP model follows the overall Habitat Evaluation Procedure (HEP) model concepts developed by the U.S. Fish and Wildlife Service (USFWS) to evaluate the quantity and quality of habitat available for a species of concern (USFWS, 1980a,b; USFWS, 1981). In general, a Habitat Evaluation Procedure (HEP) model uses measurable attributes of habitat quality and quantity to create relationships between habitat suitability and animal occurrence and density. The suitability relationships are converted into standardized Habitat Suitability Indices (HSI) that encompass the range of observed habitat conditions. Habitat quality is assessed based on the HSI values and habitat quantity is defined based on area, which when multiplied, provide overall habitat units (HUs) for a given area. This process may be used to assess changes associated with different management scenarios for a specific area, or to allow comparison across multiple sites. The HSHEP merges this traditional HEP approach with multi-spatial modeling capabilities for Hawaiian streams (Parham, 2002; Kuamo'o et al., 2006; Parham, 2008). The multi-spatial component addresses issues of scale in understanding differences in habitat availability and species distribution.

A detailed description of the HSHEP model development and design is provided in Attachment 1. The USACE Ecosystem Center of Expertise (ECO-PCX) reviewed this information, and granted approval for its use on the Ala Wai Canal Project on May 19, 2015 (Attachment 2).

2.2 Methodology

Detailed stream and fish surveys to support the HSHEP modeling effort were conducted by aquatic biologists, Dr. James Parham (Bishop Museum) and Glenn Higashi (DAR). As part of this effort, the streams in the Ala Wai Watershed were surveyed, including approximately 8.7 kilometers of Manoa Stream, 1.6 kilometers of Makiki Stream, and 3.7 kilometers of Palolo Stream. The stream surveys were recorded using high-definition video, and the survey data were subsequently processed according to the variables in the HSHEP model. Using the HSHEP model, the habitat suitability was then determined for each of the native aquatic species along approximately each meter of stream; the average suitability was then calculated for defined stream segments. A combination of the habitat suitability and the area of each segment were then used to calculate HUs for each individual species, as well as for the combination of all native species within each segment.

Despite the robust dataset available for native species in Hawaii's streams, there is still some degree of inherent uncertainty in the underlying assumptions used to model habitat quality. In particular, the extent to which in-stream structures restrict upstream migration (e.g., in response to varying flow regimes over time) has not previously been quantified, but has an important bearing on the modeling of upstream habitat quality. As such, the resource agencies requested consideration of different assumptions of species passage, in order to better understand the possible range of resulting habitat quality values. In response to this request, both the "expected scenario" and a "worst-case scenario" were modeled, as described below.

- The "expected scenario" reflects the project team's best professional judgement; it assumes that existing in-stream structures with an overhanging lip create a passage barrier for native species 50% of the time, and channelized reaches reduce passage by 10% for every 100 meters. These assumptions were used as the basis for calculation of the baseline impact and evaluation of mitigation requirements.
- The "worst-case scenario" reflects a more conservative set of assumptions that overhanging structures only allow for passage of native species approximately 35% of the time, and

channelized reaches reduce passage by 15% for every 100 meters. This scenario is intended to bound the range of possible conditions, thus providing a basic sensitivity analysis of the model results. It was used as a means to validate the outcomes of the mitigation development process (that is, to confirm that the mitigation would still adequately compensate for the habitat impacts even with a more conservative set of assumptions).

The model results for the existing and future-without project condition, as well as the conditions based on implementation of the tentatively selected plan are presented below. Application of the model for the mitigation measures is discussed in Section 3.3. Additional detail regarding model application is provided in Attachment 3.

2.3 Model Results

2.3.1 Existing and Future Without-Project Condition

Based on the methodology described above, the HSHEP model was used to determine existing quality of the streams and associated aquatic habitat within the Ala Wai Watershed. The analysis also considered the future without-project condition (i.e., the most likely condition expected to exist in the future in the absence of the proposed project), as this defines the benchmark against which alternative plans are evaluated.

Future changes in watershed and stream conditions have the potential to influence the amount and/or quality of freshwater stream habitat. For example, future watershed improvements could positively influence stream health, thus increasing habitat quality over time. Conversely, continued degradation could reduce the amount and/or quality of stream habitat. Based on the extent of existing urbanization and development within the Ala Wai Watershed, and more specifically along the streams, it is expected that further development will be minimal. Some degree of redevelopment may occur in the neighborhoods throughout the watershed, however this is not expected to substantially affect the physical or biological characteristics of the streams. While there may be some slight changes in localized conditions, the overall species composition and habitat structure is not expected to change dramatically over the period of analysis. Therefore, for the purposes of this analysis, it is assumed that habitat conditions will remain relatively constant over time, such that the HUs associated with the existing and future without-project conditions will be commensurate.

The HUs associated with the existing and future without-project conditions are summarized in Table 1; a detailed discussion of the results is provided in Attachment 3.

TABLE 1
Habitat Units Associated with the Existing and Future Without-Project Condition

Location	Habitat Units (HUs)	
	Expected Scenario	Worst-Case Scenario
Manoa Stream	36,713	35,391
Palolo Stream	1,377	834
Makiki Stream	7,800	7,495
Hausten Ditch	8,681	8,681
Total	**54,572**	**52,401**

2.3.2 Tentatively Selected Plan

The tentatively selected plan for the Ala Wai Canal Project is comprised of a series of flood risk management measures, including debris and detention basins, debris catchment structures, flood walls, and improvements to the flood warning system. A description of each measure and the estimated area of impact is provided in Table 2. A detailed discussion of the tentatively selected plan (and the plan formulation process) is provided in the Draft Feasibility Report/EIS.

The characteristics of the proposed measures were used to define changes in habitat quality using the HSHEP model, as needed to calculate HUs based on implementation of the tentatively selected plan. Changes in habitat quality associated with implementation of the tentatively selected plan include potential loss of aquatic habitat (e.g., due to placement of structures within the stream) and decreased passage for native aquatic species. As described in Section 3.6 of the Draft Feasibility Report/EIS, design features have been incorporated to avoid and minimize these impacts to the extent practicable (e.g., use of natural bottom arch culverts to maintain species passage); however, some degree of impact is unavoidable. The anticipated changes in habitat conditions were based on professional judgment of the project team, including input from the resource agencies.

Key assumptions that were made as part of the HSHEP modeling of the with-project condition are listed below. The assumptions were discussed and agreed upon with the resource agencies (as part of a meeting with USFWS and DAR on January 23, 2015), and were subsequently refined as part of the model application process.

- The area to be impacted by each measure was defined as the length of stream within the permanent structure footprint plus the area needed for O&M (generally the entire length of stream within the construction limits).
    - The aquatic habitat to be impacted by the Kanewai Detention Basin and the Ala Wai Golf Course Detention Basin is limited to the streambank within the notched spillway footprint.
    - The Ala Wai Canal floodwalls will not result in any impacts to the aquatic environment.
    - Improvements to the flood warning system will involve negligible work in the streams; as such, it is assumed there would be no impact to the aquatic environment.
- To be conservative, it has been assumed that habitat for aquatic species would be entirely eliminated within the permanent footprint of the debris catchment and detention structures (and stand-alone debris catchment structures), but that species passage would be maintained via a natural bottom arch culvert.
    - Within the area to be excavated behind the Waiomao Debris and Detention Basin, a low-flow channel will be reformed and the existing substrate will be replaced following construction. Recognizing that there could be some degree of long-term habitat degradation associated with the excavation (and ongoing vegetation management), it is assumed that there would be an approximately 50% decrease in habitat quality within this area. The “worst-case scenario” assumes 100% loss of habitat within the area to be excavated.
    - An in-stream structure associated with an abandoned USGS gaging station is located within the area to be excavated for the Waiomao Debris and Detention Basin, and will be removed as part of project construction. This in-stream structure is a barrier to upstream passage of native species, and its removal will provide habitat benefits by increasing accessibility to upstream habitat (thereby offsetting some of the habitat losses). This benefit is reflected in the with-project condition.
    - It is assumed that there would be an approximately 20% loss of habitat quality within the reach directly affected by the notched spillways for the Kanewai and Ala Wai Golf Course detention basins. The “worst-case scenario” assumes 100% loss of habitat within these reaches.

TABLE 2
Flood Risk Management Measures Included in the ~~Tentatively Selected~~ Recommended Plan

Flood Risk Management Measure	Description of Measure	Operations and Maintenance (O&M) Requirements	Length of Stream Within Construction Limits (linear feet)	Length of Stream Within Permanent Structure Footprint (linear feet)	Length of Stream Within O&M Area (linear feet)
Waihi Debris and Detention Basin	Earthen ~~dam~~structure , approximately ~~24'~~42 feet high and ~~225'~~477 feet across; arch culvert to allow small storm flows to pass; concrete spillway above culvert with grouted rip rap on upstream and downstream side; debris catchment feature located on upstream end of culvert~~.~~; approximately 150 feet of riprap for energy dissipation and scour protection downstream of culvert. New access road to be constructed for construction and O&M.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of berm) twice per year, allowing no woody vegetation to grow in this area. Clear accumulated debris following flood event and annually.	160	130	40
Waiakeakua Debris and Detention Basin	Earthen ~~dam~~structure, approximately ~~20'~~37 feet high and ~~185'~~401 feet across; arch culvert to allow small storm flows to pass; concrete spillway above culvert with grouted rip-rap on upstream and downstream side; debris catchment feature located on upstream end of culvert; approximately 150 feet of riprap for energy dissipation ~~structure to be located on~~ downstream~~-end~~ of culvert.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of berm) twice per year, allowing no woody vegetation to grow in this area. Clear accumulated debris following flood event and annually.	190	110	40
Woodlawn Ditch Detention Basin	Three-sided berm, approximately 15~~'~~ feet high and 840~~'~~ feet across; arch culvert to allow small storm flows to pass; concrete spillway above culvert with grouted rip rap on upstream and downstream side~~; 20-foot-wide perimeter to be maintained as cleared around perimeter of berm and potential flooded area~~.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of berm) twice per year, allowing no woody vegetation to grow in this area.	120	60	40
~~Manoa~~ Mānoa In-Stream Debris Catchment	Concrete pad, approximately 8~~'~~ feet wide and 60~~'~~ feet across; steel posts (up to approximately 7~~'~~ feet high) evenly spaced 4~~'~~ feet apart along concrete pad.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of concrete) twice per year, allowing no woody vegetation to grow in this area. Clear accumulated debris following flood event and annually.	48	8	40
Kanewai Field Multi-purpose Detention Basin	Earthen berm, approximately 7~~'~~ feet high, around 3 sides of the field; grouted rip-rap inflow spillway along bank of ~~Manoa~~Mānoa Stream to allow high flows to enter the basin; existing drainage pipe at south end of basin to allow water to re-enter stream.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of berm) twice per year, allowing no woody vegetation to grow in this area. Area within berm to be maintained as a field for park use (with no woody vegetation) during non-flood conditions.	70	70	0
~~Waiomao~~ Waiʻōmaʻo Debris and Detention Basin	Earthen ~~dam~~structure, approximately ~~24'~~34 feet high and ~~120'~~275 feet across; ~~arch~~box culvert to allow small storm flows to pass; concrete spillway above culvert, with grouted rip rap on upstream and downstream side debris catchment feature located on upstream end of culvert; approximately 150 feet of riprap for energy dissipation and scour protection downstream of culvert. Excavation of ~~approx. 2,015 cubic yards~~ approximately 3,060 yd^3 to provide required detention volume upstream of berm;~~ low-flow channel with existing substrate to be restored following excavation.~~ New access road to be constructed for construction and O&M.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of dam and excavation area) twice per year, allowing no woody vegetation to grow in this area. Clear accumulated debris following flood event and annually.	455	130	40
~~Pukele~~ Pūkele Debris and Detention Basin	Earthen ~~dam~~structure, approximately ~~24'~~35 feet high and ~~120'~~82 feet across; ~~arch~~box culvert to allow small storm flows to pass; concrete spillway above culvert with grouted rip rap on upstream and downstream side; debris catchment feature located on upstream end of culvert~~.~~; approximately 150 feet of riprap for energy dissipation and scour protection downstream of culvert. Excavation of approximately 14,330 yd^3 to provide required detention volume upstream of berm; New access road to be constructed for construction and O&M.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of dam) twice per year, allowing no woody vegetation to grow in this area. Clear accumulated debris following flood event and annually.	170	130	40
Makiki Debris and Detention Basin	Earthen ~~dam~~structure, approximately ~~24'~~36 feet high and 100~~'~~ feet across; arch culvert to allow small storm flows to pass; concrete spillway above culvert with grouted rip-rap on upstream and downstream side; debris catchment feature located on upstream end of culvert~~.~~; approximately 150 feet of riprap for energy dissipation and scour protection downstream of culvert. Excavation of approximately 3,035 yd^3 to provide required detention volume upstream of berm; New access road to be constructed for construction and O&M.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of dam) twice per year, allowing no woody vegetation to grow in this area. Clear accumulated debris following flood event and annually.	175	130	40
Ala Wai Canal Floodwalls	Concrete floodwalls ranging up to approximately ~~5~~4 feet high, offset from existing Canal walls. Existing stairs to be extended and new ramps to be installed to maintain access to Canal; floodgate to be installed near McCully Street. ~~Three~~Two pump stations to accommodate storm flows and gates installed at existing drainage pipes to prevent backflow from the Ala Wai Canal during a flood event.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of floodwalls) twice per year, allowing no woody vegetation to grow in this area. Periodically inspect drainage pipes and gates, and remove any impediments to movement. Paint and/or grease metal parts, as needed.	0	0	0
Hausten Ditch Detention Basin	Concrete floodwalls and an earthen berm (approximately 4.3~~'~~ feet high) to provide detention for local drainage; install concrete wall with four slide gates adjacent to the upstream edge of the existing bridge to prevent a backflow from the Ala Wai Canal during a flood event.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of berm and floodwalls) twice per year, allowing no woody vegetation to grow in this area. Area within berm to be maintained as a field for recreational use during non-flood conditions. Periodically inspect slide gates and actuators and remove any impediments to movement. Paint and/or grease metal parts, as needed.	70	35	35

TABLE 2
Flood Risk Management Measures Included in the ~~Tentatively Selected~~ Recommended Plan

Flood Risk Management Measure	Description of Measure	Operations and Maintenance (O&M) Requirements	Length of Stream Within Construction Limits (linear feet)	Length of Stream Within Permanent Structure Footprint (linear feet)	Length of Stream Within O&M Area (linear feet)
Ala Wai Golf Course multi-purpose detention basin	Earthen berm, ~~up to approximately 7'~~ on average 2.7 feet high, around the north and east perimeter of the golf course; grouted rip rap inflow spillway along bank of ~~Manoa Palolo~~ Mānoa-Pālolo Drainage Canal to allow high flows to enter the basin; sediment basin within western portion of golf course; floodgate across the main entrance road; passive drainage back into Ala Wai Canal.	Cut/clear vegetation within cleared zoned (20 feet around perimeter of levee) twice per year, allowing no woody vegetation to grow in this area. Area within berm to be maintained as a golf course (with no woody vegetation in sediment basin) for recreational use during non-flood conditions. Periodically inspect floodgate and remove any impediments to movement. Paint and/or grease metal parts, as needed. Inspect, test, and maintain pump system annually. Paint and/or grease metal parts, as needed.	70	70	0
Floodwarning system	~~Improvements to existing flood warning system in Ala Wai Watershed, including i~~Installation of 3 real-time rain gages (~~Manoa~~Mānoa, Makiki and ~~Palolo~~ Pālolo Streams) and 1 real-time streamflow or stage gage (Ala Wai Canal)~~; exact locations to be determined~~ as part of flood warning system for Ala Wai Watershed.	Periodically inspect gages for proper operating conditions. Keep area around sensors free from sediment deposits and plant growth, or other impediments to data collection.	0	0	0

- The debris and detention structures are not designed to trap sediment (except for the sediment basin at the Ala Wai golf course). Therefore, it has been assumed that there would be no substantial changes in substrate/embeddedness in downstream habitat.
- The inundation area behind each detention structures is not included as part of the impact area. Inundation of these areas would be infrequent and short in duration; for example, inundation resulting from the 1% annual chance exceedance (ACE) flood would last less than 12 hours. As such, there are expected to be little to no potential effects to stream habitat and aquatic species.

The results of the HSHEP modeling for the with-project condition are summarized in Table 3; a detailed discussion of the results is provided in Attachment 3. Based on a comparison of these results to those for the future without-project condition, implementation of the project is expected to result in a loss of 192 HUs as shown in Table 3.

As it is expected that the impacts would be immediately realized following construction of the project features (i.e., there would not be a delay or “compounding” effect on habitat quality over time), it is therefore assumed that habitat conditions would remain constant over the life of the project.

TABLE 3
Loss of Habitat Units Associated with Implementation of the Tentatively Selected Plan (As Compared to the Future Without-Project Condition)

Location	Habitat Units (HUs)				
	Existing Conditions	With-Project Conditions			Net Loss
		Lost	Gained[a]	Total	
EXPECTED SCENARIO					
Manoa Stream	36,713	191	0	36,522	**191**
Palolo Stream	1,377	11	118	1,484	**-107**
Makiki Stream	7,800	24	0	7,777	**24**
Hausten Ditch	8,681	84	0	8,597	**84**
Total	**54,572**	**310**	**118**	**54,380**	**192**
WORST-CASE SCENARIO					
Manoa Stream	35,391	808	0	34,584	**808**
Palolo Stream	834	3	32	863	**-29**
Makiki Stream	7,495	11	0	7,484	**11**
Hausten Ditch	8,681	420	0	8,261	**420**
Total	**52,401**	**1,242**	**32**	**51,192**	**1,210**

Note:
[a] The “expected scenario” reflects the project team’s best professional judgement, and serves as the basis for calculation of the baseline impact and evaluation of mitigation requirements. The “worst-case scenario” reflects a more conservative set of assumptions and is intended to provide a basic sensitivity analysis of the model results (to help validate the outcomes of the mitigation development process).
[b] The anticipated gain of HUs for the with-project condition is associated with removal of an abandoned USGS gaging station within the area to be excavated for the Waiomao Debris and Detention Basin. This in-stream structure is a barrier to upstream passage of native species, and its removal will provide habitat benefits by increasing accessibility to upstream habitat.

3.0 Description of Proposed Mitigation

3.1 Mitigation Objectives

Based on the type of habitat to be impacted, and within the context of the habitat requirements for native Hawaiian aquatic species (as defined in the HSHEP model), the following objectives were developed to guide the mitigation development effort:

- Restore and/or enhance physical conditions to improve in-stream habitat for native Hawaiian aquatic species
- Improve passage for native Hawaiian aquatic species to increase access to upstream areas of high-quality habitat

In consultation with the resource agencies, it was determined that application of these mitigation objectives should not be limited to the specific habitat parameters or areas impacted by the project, but rather should be considered within the context of the overall watershed. In other words, the mitigation development process should entail a watershed approach, wherein the conditions throughout the watershed are assessed to identify those habitat parameters and locations where mitigation might provide the greatest benefit for native aquatic species as a whole.

3.2 Mitigation Development Approach

To support the mitigation development effort, a framework was developed based on a series of iterative tasks informed by the stream surveys and HSHEP modeling results. Each task was conducted within the context of the SMART planning approach employed for the overall flood risk management project, as described in the Draft Feasibility Report/EIS. First, as shown in Figure 1, the key stressors and primary factors limiting habitat quality for native aquatic species in the Ala Wai Watershed were broadly defined based on best professional judgment and the results of the stream surveys. This information was used as the basis for identifying potential mitigation concepts, or actions that could be implemented to address the various stressors. Using the HSHEP model results for the existing conditions, these concepts were further refined and applied to site-specific locations. A site visit was conducted for each of the potential mitigation locations to validate and refine the mitigation concept. In addition, other relevant information was gathered, including land ownership and existing channel maintenance activities. This information was then considered as part of a detailed screening process, which involved a comprehensive set of criteria (based on those used for the overall flood risk management project, and tailored to the mitigation effort). Those measures carried forward from the screening process were then combined into various mitigation alternatives that could be implemented to compensate for the habitat impacts associated with the overall flood risk management project. Conceptual design drawings were prepared for the range of mitigation measures/alternatives (to an approximately 10 percent level of design), based upon which cost estimates were developed. In addition, the habitat benefits associated with each alternative were quantified using the HSHEP model. The costs and benefits were then used as inputs to a CE/ICA, which provided the basis for selection of the mitigation alternative for implementation. The resource agencies were consulted throughout this process, and their input was incorporated as appropriate. The results of this process are described in the subsequent sections.

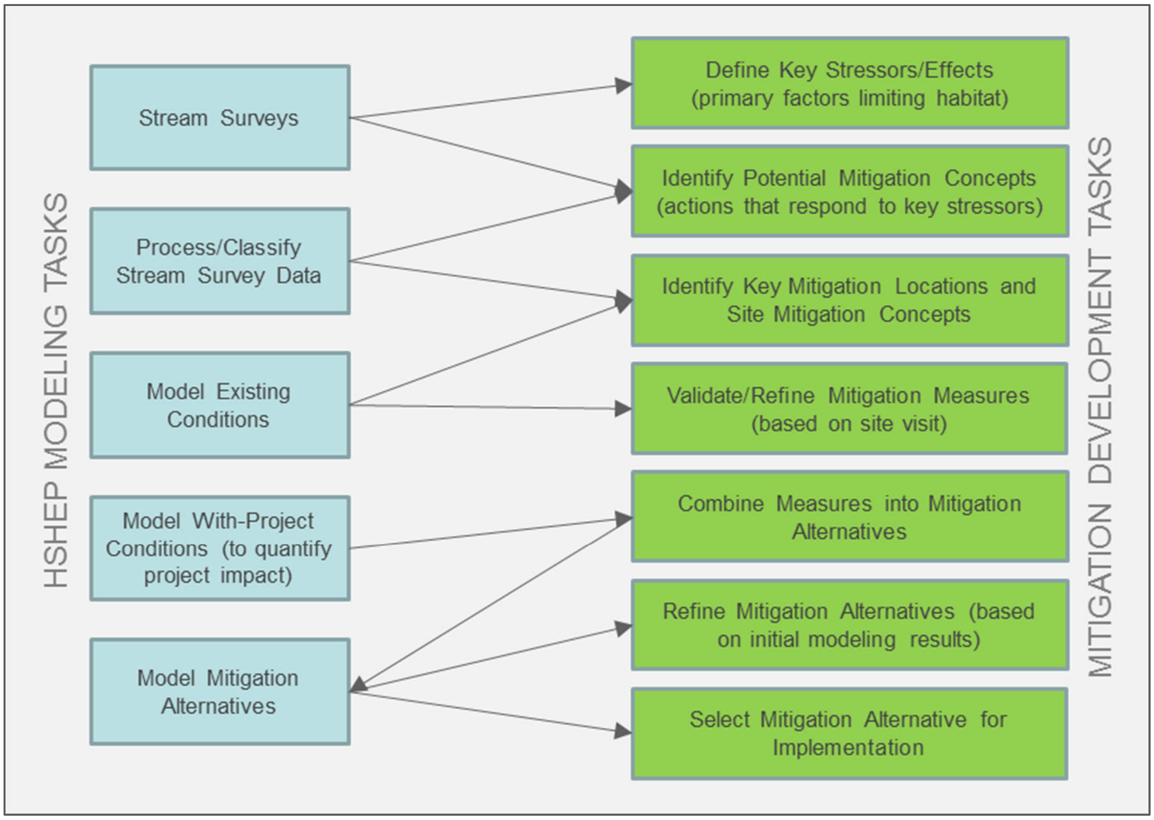


FIGURE 1
Overview of the HSHEP Modeling and Mitigation Development Process

3.3 Development of Mitigation Measures/Alternatives

3.3.1 Mitigation Concepts

As described above, the initial list of mitigation concepts was developed in response to the primary factors believed to be limiting habitat quality for native aquatic species in the Ala Wai Watershed; this effort was primarily based on best professional judgment and the results of the stream surveys. The list of initial mitigation concepts is provided in Table 4.

It is important to note that there are some stressors that are generally understood to be contributing to degradation of Hawaii's stream habitat and faunal assemblage, but were determined to either be outside the scope of mitigation efforts for this project or are not considered key limiting factors in the Ala Wai Watershed (given other overriding conditions). These include prevalence of invasive aquatic species and inputs of stormwater runoff. Although both of these stressors are common throughout the Ala Wai Watershed, it was determined that the project could result in a limited response to these conditions, and as such, mitigation efforts should focus on key strssors related to physical habitat conditions.

TABLE 4
Initial Mitigation Concepts

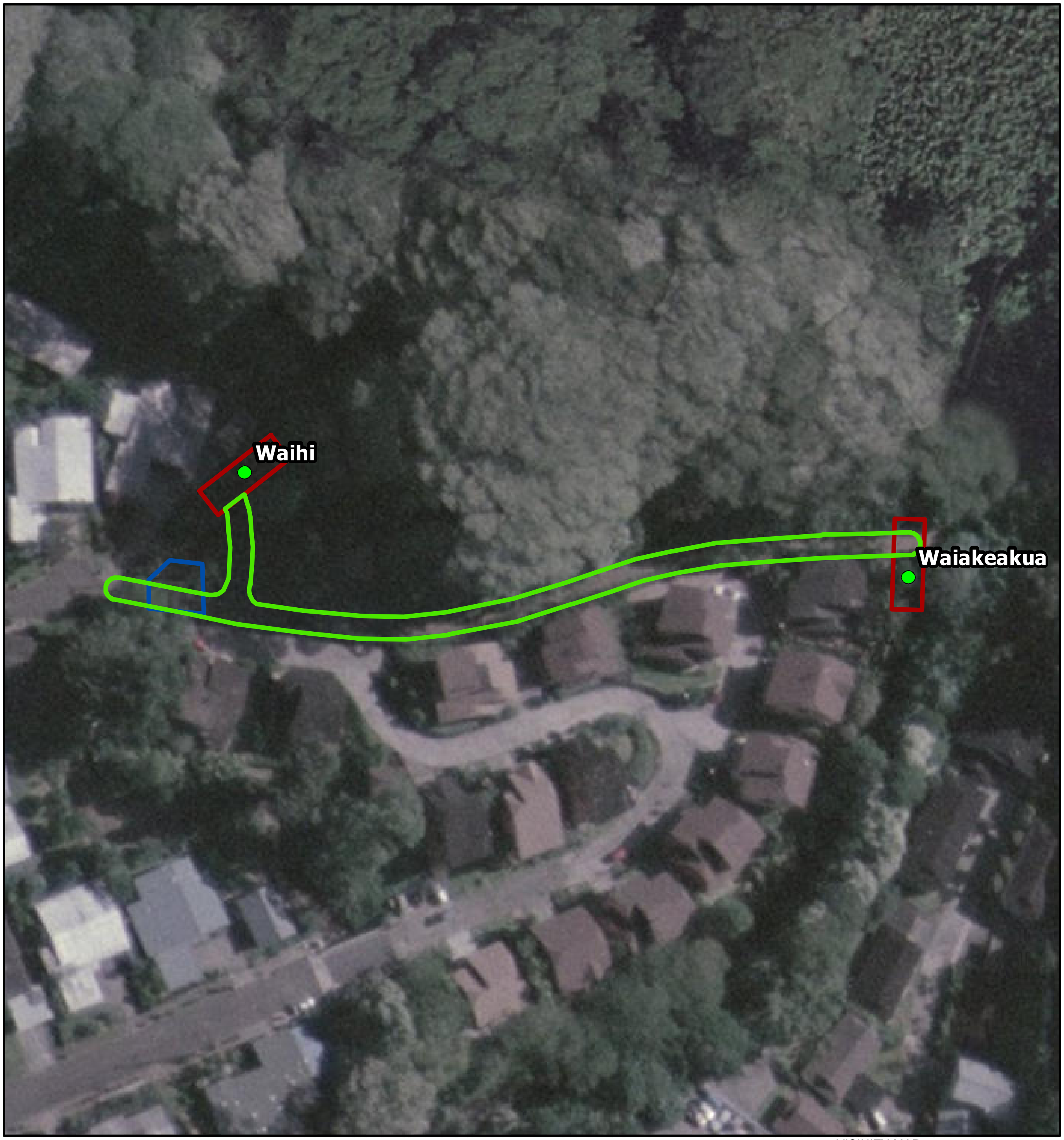
Response to Key Stressors	Mitigation Concept
Improve migratory pathway	Remove passage barrier (e.g., overhung structures)
	Install low-flow channel along channelized reach
	Install resting riffles along channelized reach
Improve in-stream habitat	Add new habitat pools in channelized reach
	Enhance existing in-stream habitat in unchannelized reach
Provide bank stabilization	Stabilize exposed/eroding banks
	Stabilize failing walls
Improve riparian habitat	Restore/enhance riparian habitat

The initial concepts were further reviewed and validated within the context of the HSHEP model source data and preliminary results for the existing habitat conditions. Through this effort, several of the concepts were eliminated from further consideration, as follows:

- **Enhance existing in-stream habitat in unchannelized reach:** Although there are reaches of unchannelized habitat with less than ideal conditions (e.g., degraded channel form, presence of trash, etc.), the results of the stream surveys indicate that these reaches still provide adequate habitat for native aquatic species, especially when compared to channelized reaches. As such, it was determined that enhancement of habitat in unchannelized reaches would not address a key stressor for native aquatic species in the Ala Wai Watershed.
- **Stabilize failing walls:** Although a wall failure could certainly affect in-stream habitat, should one occur, it was determined that stabilization of existing channel infrastructure is more of a channel maintenance issue than a habitat management issue. Therefore, this measure was eliminated from further consideration.
- **Restore/enhance riparian habitat:** Given the heavy urbanization and encroachment of development in the areas directly adjacent to the streams, there is very little opportunity for restoration of the riparian corridor in the Ala Wai Watershed without extensive land acquisition (which is beyond the scope of mitigation for this project). Although dominated by non-native species, the extant riparian habitat is not believed to be key limiting factor relative to in-stream habitat quality for native aquatic species (especially when considered in context with other factors, such as channelization). As such, this measure was also eliminated from further consideration.

3.3.2 Preliminary Mitigation Measures

The remaining mitigation concepts were carried forward for further consideration, and based on the review of the HSHEP model source data and preliminary results, key areas for habitat improvement were identified based on those concepts. This information was used as the basis for siting each of the mitigation concepts in locations where habitat benefits could be maximized. A site visit was conducted for each of the potential mitigation locations to validate and refine the various mitigation concepts. The resulting measures are summarized in Table 5, and the locations are shown in Figure 2.



LEGEND

Impact Area Description

- **Construction Limits**
- **Access**
- **Staging**

Notes:
1. Area of interest subject to change.

N

0 50 100
Feet

VICINITY MAP

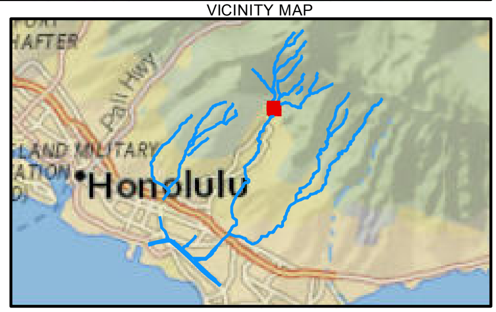


FIGURE 2a
Falls 11 and 12
Mitigation Measure Impact Areas
Ala Wai Watershed

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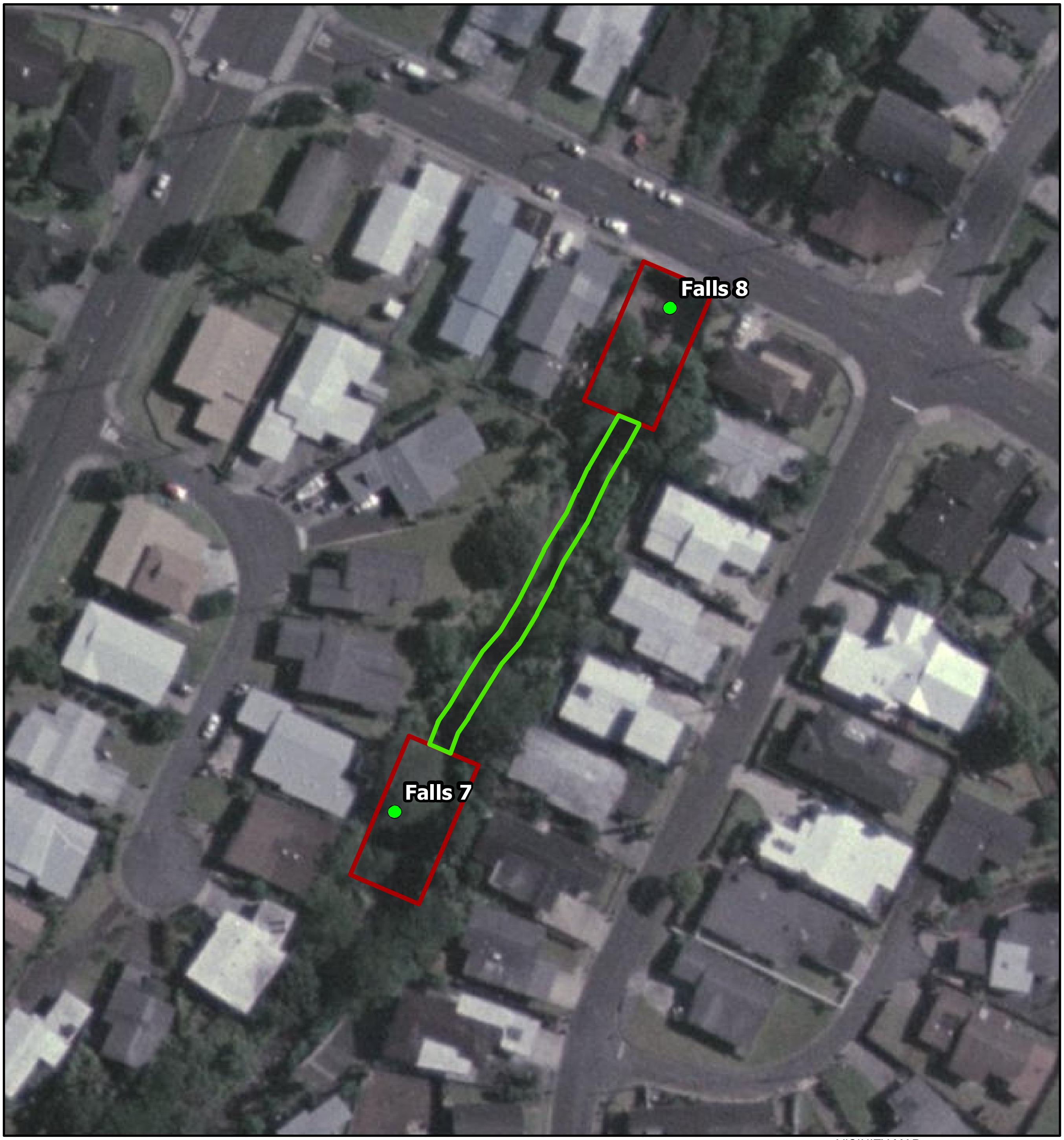


LEGEND

Impact Area Description

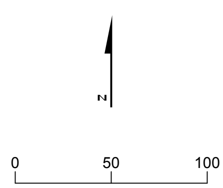
Construction Limits

Access

Staging

Notes:

1. Area of interest subject to change.



VICINITY MAP

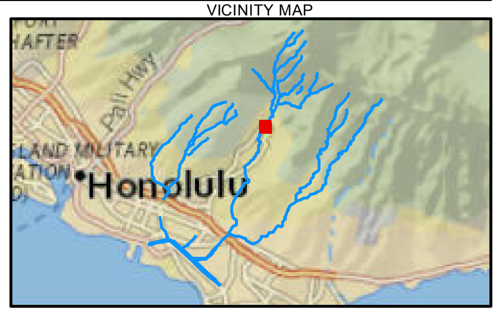


FIGURE 2b

Falls 7 and 8

Mitigation Measure Impact Areas

Ala Wai Watershed

CH2MHILL

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LEGEND

Impact Area Description

Construction Limits

Access

Staging

Notes:

1. Area of interest subject to change.

N

0 100 200

Feet

VICINITY MAP

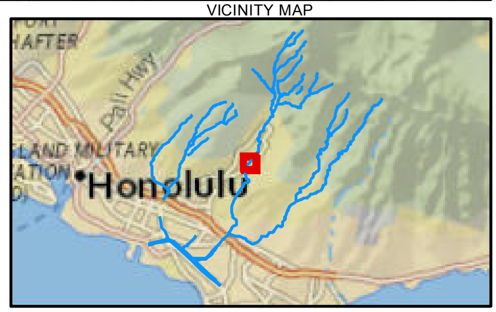

FIGURE 2c

Manoa Concrete Channel

Mitigation Measure Impact Areas

Ala Wai Watershed

CH2MHILL.

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TABLE 5
Preliminary Mitigation Measures

Mitigation Measure	Location	Description
Remove Passage Barrier		
Falls 6	Manoa Stream, approximately 0.3 mile upstream of Manoa District Park	Remove overhanging lip associated with undercutting at existing utility line crossing
Falls 7	Manoa Stream, approximately 0.6 mile upstream of Manoa District Park	Remove overhanging lip associated with undercutting at existing in–stream structure
Falls 8	Manoa Stream, approximately 0.7 mile upstream of Manoa District Park	Remove overhanging lip associated with undercutting at existing in–stream structure
Falls 11	Waihi Stream, at USGS gaging station	Remove overhanging lip associated with undercutting at existing USGS gaging station
Falls 12	Waiakeakua Stream, at USGS gaging station	Remove overhanging lip associated with undercutting at existing USGS gaging station
Falls P5	Waiomao Stream, at USGS gaging station	Remove overhanging lip associated with undercutting at existing USGS gaging station
Install Low-flow Channel and/or Habitat Pools Along Channelized Reach[a]		
Manoa Stream	Approx. 1100 feet of concrete channel downstream of Manoa District Park	Notch low-flow channel and/or habitat pools into concrete and add natural substrate
Palolo Stream	Approx. 1.5 miles of concrete channel through Palolo Valley	Notch low-flow channel and/or habitat pools into concrete and add natural substrate
Install Resting Riffles Along Channelized Reach[a]		
Manoa Stream	Approx. 1100 feet of concrete channel downstream of Manoa District Park	Mount low-profile curbs onto surface of concrete to create pockets of resting habitat
Palolo Stream	Approx. 1.5 miles of concrete channel through Palolo Valley	Mount low-profile curbs onto surface of concrete to create pockets of resting habitat
Bank Stabillization		
Manoa Stream	Above Kahaloa Bridge near Manoa District Park	Reduce slope and install geotextile fabric and vegetation to stabilize ~300 feet of eroding bank

NOTE:
[a] Installation of a low-flow channel, habitat pools and/or resting riffles was initially considered for the channelized reach of Makiki Stream. However, it was determined that the extensive section of underground channel that is upstream of the channelized reach would severely limit the benefits gained by these measures. As such, these measures were eliminated from further consideration.

3.3.3 Screening and Refinement of Mitigation Measures

In order to ensure that the mitigation measures carried forward for further consideration meet a set of minimum standards, a detailed screening process was conducted. This process utilized a comprehensive set of criteria based on those used for the overall flood risk management project (which were defined within the context of the federal criteria specified in the Engineer Regulation [ER] 1105-2-100; “USACE Planning Guidance Notebook”) and tailored to the mitigation effort. The screening criteria that were applied to the mitigation measures are summarized in Table 6.

TABLE 6
Criteria Used to Screen Mitigation Measures

Criteria	Description
Technical feasibility	Is it feasible/viable to construct measure?
Application in Hawaii	Has the measure been successfully applied in Hawaii?
Compatibility/Dependency	Is the measure dependent on another action to be functional?
Flood reduction	Does measure substantially increase potential for flooding?
Implementation cost[a]	What is the ROM cost to construct the measure?
Cost effectiveness[a]	Is the habitat gain worth the cost?
Land availability and ownership	Is there enough space to implement measure (including staging/access?)
	Is the land owned by State/C&C or a few private landowner?
	Can real estate rights be reasonably obtained?
O&M requirements	What is the estimated level of effort (need for new practice/equipment)?
	Would the measure conflict with existing O&M practices?
Acceptability	Will the measure displace people/activities? It is legally acceptable?
Biological resources	Would the measure adversely affect any known sensitive biological resources?
	Would the measure increase the potential for passage of non-native (invasive) species?
Historic/archaeological resources	Would the measure adversely affect any known historic/archaeological resources?
Sediment contamination	Would the measure be located in an area with known (or high potential for) sediment contamination?

NOTE:
[a] Recognizing that the purpose of the CE/ICA is to provide a quantifiable basis for evaluation of cost-effectiveness, the criteria related to implementation cost and cost-effectiveness were used to screen out measures that were considered to be excessively expensive or ineffective, so as to focus the mitigation development effort on reasonable and practicable mitigation solutions, consistent with the SMART planning approach.

The information required to complete the screening process was subsequently compiled, including consultation and coordination with State and County agencies, and other entities as needed. This effort resulted in the elimination of the measures listed below; the detailed screening results are contained in Attachment 4. In addition, based on additional information obtained through consultation, it was determined that two of the measures were no longer warranted, such that they were also eliminated from further consideration, as listed below.

- **Remove Passage Barrier at Falls 6:** Based on coordination with the City & County of Honolulu, it was determined that the Department of Facilities Maintenance (DFM) is in the process of resolving the erosion and undercutting associated with this structure. The design effort has been completed and the proposed design is expected to adequately address fish passage requirements; therefore, this measure was eliminated from further consideration (and instead is reflected in the future without-project conditions).
- **Remove Passage Barrier at Falls P5:** The specific location of this structure was verified based on the stream survey data, and was determined to be within the footprint of the excavation area for the Waiomao Debris and Detention Basin. It was confirmed that the

structure would be removed as part of construction of the debris and detention basin, such that the mitigation measure was eliminated from further consideration (and instead is reflected in the with-project condition).

- **Install Low-Flow Channel, Habitat Pools and/or Resting Riffles Along Channelized Portion of Palolo Stream:** Based on initial review of the real estate requirements, it was determined that this measure involved a multitude of property owners, and obtaining the real estate rights would require extensive coordination and would be cost-prohibitive. Therefore, these measures were eliminated from further consideration.

The remaining measures were carried forward for further consideration as part of the identification of mitigation alternatives.

3.3.4 Conceptual Design of Mitigation Measures

For the measures carried forward from the screening process, conceptual design drawings were developed to a 10-percent level of design. This effort incorporated the best available information and collective knowledge of the habitat requirements for native aquatic species; it also considered lessons learned from other past projects and input from the resource agencies. Key design considerations are discussed below.

The passage barrier removal design was based on previous passage barrier removal efforts completed by DAR (and others) on Waihe'e Stream (see Figure 3). Based on information gained from this successful effort, the measure would restore a near vertical surface to the face of the existing in-stream structure, which is expected to allow for native aquatic species passage, while deterring upstream passage of non-native species. It would be comprised of non-systematic placement of grouted stones that would mimic natural stream features and allow multiple pathways for water flow.

FIGURE 3
Previous Passage Barrier Removal Efforts on Waihe'e Stream (photos provided by Glenn Higashi [DAR])

The design for installation of in-stream habitat and passage within the channelized reach of Manoa Stream incorporates design features and dimensions based on best professional judgment regarding native species habitat requirements. Specifically, the conceptual designs assume that up to 6 inches of water is required to maintain passage (e.g., for the resting riffles), and at least 18 inches of water is needed to provide in-stream habitat (e.g., for the habitat pools and low-flow channel); the dimensions and spacing of these features reflects characteristics of natural stream habitat. Passage and/or habitat would be installed over the full 1,100 feet of the channelized reach in Manoa Stream; given the mitigation objectives, shorter increments were not considered.

The 10-percent design drawings for each of the mitigation measures carried forward from the screening process are contained in Attachment 5.

3.3.5 Identification of Mitigation Alternatives

Based upon the 10-percent design concepts, the mitigation measures were then combined into alternatives that could be implemented to adequately compensate for the habitat impacts associated with the overall flood risk management project. Specifically, this effort sought to identify alternatives comprised of measures that either alone or in combination would provide a gain of HUs equal to or greater than the loss of HUs anticipated from implementation of the tentatively selected plan, thus compensating for the loss of habitat quality associated with project implementation. Recognizing that there are many possible measure combinations, consistent with SMART planning principles, a focused number of alternatives were defined based on estimated habitat benefits and functionality, as discussed below.[2]

Given the limited passage allowed by existing in-stream barriers, removal of a barrier is expected to provide little to no benefit to native aquatic species if downstream barriers are still in place. Therefore, the alternatives were formulated to only include combinations of barrier removal starting at the furthest downstream barrier (i.e. Falls 7) and moving upstream. Possible alternatives involving removal of upstream barriers with downstream barriers still in place were not considered (e.g., Falls 8, 11 and/or 12). As Falls 11 and 12 are located on separate tributaries to Manoa Stream, they were combined with Falls 7 and 8, both in parallel and together. As preliminary analyses indicated that the concrete channel improvements were not cost effective, they were not considered in combination with any other measures. Based on these concepts, the following alternatives were identified:

- Remove passage barrier at Falls 7
- Remove passage barriers at Falls 7 and 8
- Remove passage barriers at Falls 7, 8 and 11
- Remove passage barriers at Falls 7, 8, and 12
- Remove passage barriers at Falls 7, 8, 11 and 12
- Install low-flow channel in concrete portion of Manoa Stream
- Install habitat pools in concrete portion of Manoa Stream
- Install resting riffles in concrete portion of Manoa Stream

Cost estimates were prepared for each alternative based on the conceptual design drawings. In addition, the habitat benefits were determined for each alternative, based on the HSHEP model outputs. The results of these efforts were then used to support the CE/ICA, which provided the basis for selection of the mitigation alternative for implementation. The results of this process are described in the subsequent sections.

3.4 Evaluation of Mitigation Alternatives

3.4.1 Habitat Benefits

Using the same methodology as described in Section 2, the HSHEP model was used to quantify the HUs associated with the various mitigation alternatives; the results are summarized in Table 7. As shown in Table 7, the mitigation alternatives involving removal of passage barriers provide a

[2] Although the CE/ICA software allows for all possible measure combinations to be automatically generated based on the cost and benefit of each measure, the benefits for the passage barrier removal measures are not additive, thus requiring the HSHEP model to be run for each individual measure combination.

significant increase in HUs relative to the concrete channel improvements. Despite the relatively small footprint of the barrier removal measures, the large gain of HUs reflects the overall extent of upstream habitat that would be made available to migrating native species. In contrast, the improvements along the channelized reach of Manoa Stream would only affect a relatively small, localized area.

However, in all cases, the mitigation alternatives would provide substantially more HUs than needed to offset the impacts of the flood risk management project. Because the flood risk management measures would only affect in-stream habitat within the footprint of the proposed flood risk management structures (with no anticipated impacts to species passage), a relatively small number of HUs are expected to be lost. Although the mitigation benefit would far exceed the impact of the proposed project, the mitigation alternatives reflect a reasonable range of options to improve instream habitat for native species, based on the best professional judgment of the project team. Despite the large number of HUs provided relative to the anticipated project impact, the estimated costs and level of effort of the mitigation alternatives is within the range that is appropriate for the scale and level of detail available for the proposed flood risk management project. Although different mitigation options or smaller-scale efforts that would result in fewer HUs (i.e. an increase in HUs more commensurate with the number of HUs lost) could certainly be identified, these would not address the key habitat needs identified for native aquatic species in the Ala Wai Watershed.

TABLE 7
Gain of Habitat Units Associated with Implementation of Mitigation Alternatives (As Compared to the With-Project Condition)

Location	With-Project (HUs Lost)	Mitigation Alternatives (HUs Gained)							
		Falls 7	Falls 7, 8	Falls 7, 8 and 11	Falls 7, 8 and 12	Falls 7, 8, 11 and 12	Low-Flow Channel	Habitat Pools	Resting Riffles
EXPECTED SCENARIO									
Manoa Stream	191	1,353	3,870	5,456	6,082	7,668	1,292	1,214	1,207
Palolo Stream	-107	0	0	0	0	0	0	0	0
Makiki Stream	24	0	0	0	0	0	0	0	0
Hausten Ditch	84	0	0	0	0	0	0	0	0
Total	**192**	**1,353**	**3,870**	**5,456**	**6,082**	**7,668**	**1,292**	**1,214**	**1,207**
WORST-CASE SCENARIO									
Manoa Stream	808	803	2,817	4,457	5,105	6,745	1,299	1,225	1,219
Palolo Stream	-29	0	0	0	0	0	0	0	0
Makiki Stream	11	0	0	0	0	0	0	0	0
Hausten Ditch	420	0	0	0	0	0	0	0	0
Total	**1,210**	**803**	**2,817**	**4,457**	**5,105**	**6,745**	**1,299**	**1,225**	**1,219**

3.4.2 Cost Estimates

An estimate of the implementation costs was developed as a bottom rolled-up type estimate at the conceptual (10 percent) design level, using FY2014 unit prices. In addition to the estimated costs, the CE/ICA also considers the O&M costs, as these are considered necessary to achieve the habitat benefits over the lifetime of the project. The estimated costs for each mitigation alternative is summarized in Table 8. Annualization of these costs, as needed to support the economic analysis is included in Attachment 6.

TABLE 8
Summary of Estimated Costs for Mitigation Alternatives (FY2014 Price Level)

Cost Component[1]	Falls 7	Falls 7 and 8	Falls 7, 8 and 11	Falls 7, 8 and 12	Falls 7, 8, 11 and 12	Low-Flow Channel	Habitat Pools	Resting Riffles
Construction	$67,869	$132,848	$169,801	$170,544	$207,498	$798,018	$172,393	$178,294
Real Estate	$15,900	$27,100	$32,700	$29,300	$34,900	$4,500	$4,500	$4,500
Pre-construction Monitoring	$9,250	$9,250	$9,250	$9,250	$9,250	$9,250	$9,250	$9,250
Post-construction Monitoring	$76,250	$76,250	$76,250	$76,250	$76,250	$76,250	$76,250	$76,250
O&M	$29,467	$45,712	$67,450	$67,636	$76,874	$92,301	$55,599	$57,074
Interest During Construction	$1,491	$2,918	$3,729	$3,746	$4,557	$17,526	$3,786	$3,916
Contingency[2]	$40,300	$60,118	$73,889	$74,116	$85,387	$239,055	$72,180	$73,980
Total Estimated Cost	$240,526	$354,197	$433,070	$430,841	$494,715	$1,236,900	$393,958	$403,264

NOTES:
[1] Based on FY2014 (October 2013) price levels) and 3.5% discount rate; to be updated prior to Final Feasibility Report/EIS.
[2] Assumes contingency equal to 25.5% of the construction cost plus 20% of the pre-construction monitoring, post-construction monitoring, and OMRR&R costs

3.4.3 Cost Effectiveness and Incremental Cost Analysis (CE/ICA)

As specified in the USACE regulations, the outputs of ecosystem restoration are not monetized, as is required for traditional benefit-cost analyses. Rather, evaluation of alternative restoration plans considers the relationship of habitat benefits to project costs to identify the most cost-effective plans for various levels of restoration output and provide a basis for determining whether increasing levels of restoration output are worth the added cost.

The evaluation process includes two distinct analyses to identify cost-effective and incrementally justified plans. First, the cost effectiveness analysis is conducted to identify which alternative plans have output levels that cannot be produced more cost effectively by another plan. “Cost effective” means that, for a given level of output, no other plan costs less, and no other plan yields more output for less money. Subsequently, through the incremental cost analysis, the range of plans is evaluated to arrive at a “best” level of output. The subset of cost effective plans are examined sequentially (by increasing scale and increment of output) to ascertain which plans are most efficient in the production of restoration benefits; these are referred to as “best buy plans.” They provide the greatest increase in output for the least increase in cost. That is, they have the lowest incremental cost per unit of output. The incremental analysis will not necessarily identify an optimal plan; rather, there may be a series of best buy plans. In this case, the results must be synthesized with other decision-making criteria (for example, acceptability, completeness, effectiveness, reasonableness of costs, risk and uncertainty) to provide the basis for selection of a particular plan.

The IWR Planning Suite software (IWR Plan, version 1.0.11.0) was used to conduct the CE/ICA for this project. Inputs to the CE/ICA included average annual habitat units (AAHUs) and estimated average annual cost (AAC), which are calculated based on the benefits and costs (as presented in

Tables 7 and 8, respectively) averaged over the 50-year period of analysis. As previously noted, the analysis was based on the "expected scenario."

As listed in Table 9, the results of the CE/ICA indicate that the following mitigation alternatives are cost-effective: No Action; Falls 7; Falls 7 and 8; Falls 7, 8 and 12; and Falls 7, 8, 11 and 12. Only Falls 7, 8, 11 and 12 and the No Action Alternative are considered best buy plans. A detailed discussion of the CE/ICA and the results are provided in Attachment 6.

TABLE 9
CE/ICA Results

Alternative	Estimated Cost for CE/ICA[1,2]	AAC	AAHUs	Cost-Effective	AAC/ AAHU	Best Buy?	Incremental Cost of BB Plan over Last BB Plan	Incremental Output of BB Plan over Last BB Plan	Incremental Cost/Output of Best Buy Plan
No Action	$0	$0	0	Yes	-	Yes	-	-	-
Resting Riffles	$403,264	$15,105	1,195	No	$12.64	No	N/A	N/A	N/A
Habitat Pools	$393,958	$14,753	1,202	No	$12.27	No	N/A	N/A	N/A
Low-Flow Channel	$1,236,900	$49,564	1,279	No	$38.75	No	N/A	N/A	N/A
Falls 7	$240,526	$9,014	1,340	Yes	$6.73	No	N/A	N/A	N/A
Falls 7 and 8	$354,197	$13,362	3,831	Yes	$3.49	No	N/A	N/A	N/A
Falls 7, 8 and 11	$433,070	$16,101	5,401	No	$2.98	No	N/A	N/A	N/A
Falls 7, 8 and 12	$430,841	$16,000	6,021	Yes	$2.66	No	N/A	N/A	N/A
Falls 7, 8, 11 and 12	$494,715	$18,440	7,591	Yes	$2.43	Yes	$19,102	7,783	$2.45

NOTES:

[1] The estimated costs utilized for CE/ICA are equal to the investment costs plus future costs, in present value terms. For each alternative, the investment costs include construction, real estate, PED, and construction management; future costs include post-construction monitoring, and O&M.

[2] The costs for the mitigation alternatives all fall within the estimated cost that is currently assumed for the tentatively selected plan, as described in the Cost Engineering Appendix.

3.5 Selection of Mitigation Plan

While the selected alternative need not be a best buy plan for the purposes of mitigation, it must be cost-effective; other decision-making criteria may include acceptability, completeness, effectiveness, reasonableness of costs, and risk and uncertainty. As summarized in Table 9, four of the passage barrier removal alternatives are cost-effective; only Falls 7, 8, 11 and 12 is a best buy plan (along with the No Action alternative).

Although Falls 7 alone is cost-effective, there is some degree of risk and uncertainty that this alternative would not adequately meet the required mitigation burden. Although there is assumed to be some degree of existing passage through Falls 8 (such that the habitat model indicates an adequate gain of HUs for removal of Falls 7 under the "expected scenario"), there is inherent risk in this assumption, such that it is possible that there is little to no existing passage through Falls 8. Based on this assumption, removal of Falls 7 alone would only measurably increase access to the approximately 100 meters of in-stream habitat between Falls 7 and Falls 8, and would not adequately meet the mitigation burden (as indicated by the "worst-case scenario").

Furthermore, the incremental cost per habitat unit (AAC/AAHU) drops significantly with the addition of Falls 8, such that substantially more benefits would be realized for a relatively small increase in cost. As shown in Table 9, the incremental cost of implementing Falls 7 is $6.73 per unit output, but is only $3.49 for Falls 7 and 8. Given the proximity of these features and the nature of the required work, the added cost of addressing Falls 8 is minimal, but the added benefit would be substantial (as a much greater extent of upstream habitat would be made available). Although the incremental cost of adding Falls 12 and/or Falls 11 and 12 is even lower ($2.66 and $2.43, respectively), these alternatives provide an excessive amount of habitat benefit relative to the project impacts, that the project team determined these were not worth the added cost.

These considerations, which are consistent with the USACE's Environmental Operating Principles[3] (USACE, 2012), were used the project team as the basis for selection of Falls 7 and 8 as the selected mitigation alternative for the project.

4.0 Monitoring and Adaptive Management

As specified in the guidance, monitoring includes the systematic collection and analysis of data that provides information needed to assess project performance, determine whether ecological success has been achieved, or whether adaptive management may be needed to attain project benefits. The monitoring plan should include a description of the monitoring activities, the criteria for success, and the estimated cost and duration of the monitoring (recognizing that monitoring should continue until such time as the Secretary determines that the success criteria have been met).

A preliminary description of these items is provided below. It is expected that this information would continue to be refined as the detailed designs are further refined, and the monitoring plan would be finalized during the next phase of the project.

4.1 Monitoring Approach and Activities

In order to capitalize on the detailed baseline data and comprehensive approach to quantifying aquatic habitat quality, monitoring of the mitigation efforts would involve repeated stream and fish surveys, with analysis as part of the HSHEP model. The information gathered as part of these efforts directly relate to the mitigation objectives, which focus on the physical in-stream habitat conditions and passage for native species. Specifically, the stream surveys would record the physical in-stream conditions, with the HSHEP model outputs translating those conditions into habitat quality for native aquatic species. The fish surveys would directly measure the presence and abundance of native species along the stream gradient, particularly in reaches where passage has been restored. Consideration of these data relative to the HSHEP model results would help to correlate species presence/abundance with habitat quality and passage. Direct comparison with the baseline conditions data (and each subsequent year of monitoring data) would also allow for a clear understanding of the change in conditions over time.

4.2 Performance Criteria

Performance criteria represent the desired conditions to be achieved by the end of the performance monitoring period, as needed to determine project success. To the extent possible, performance criteria should be SMART (specific, measurable, achievable, relevant, and time-bound), and include target values and ranges, as appropriate, accounting for natural variability and management actions.

[3] In particular, the USACE's Environmental Operating Principles direct the USACE to "create mutually supporting economic and environmentally sustainable solutions," as well as to "consider the environment in employing a risk management and systems approach throughout the life cycles of projects and programs."

The proposed criteria are summarized in Table 10; specific quantities for these criteria would be developed as part of the final design phase.

TABLE 10
Performance Standards and Monitoring Requirements

Mitigation Objective	Performance Criteria	Monitoring Approach
Restore and/or enhance physical in-stream conditions to improve habitat for native Hawaiian aquatic species	Increased habitat units (HSHEP); specific quantification to be determined in final design phase	Stream surveys with HSHEP model
Improve passage for native Hawaiian aquatic species to upstream areas of high-quality habitat	Increased presence (either in total, or as a percentage) of native species in upper reaches; specific quantification to be determined in final design phase; specific species include o'opu nakea, o'opu alamo'o, o'opu nopili, o'opu naniha, and o'opu akupa	Fish surveys with species counts

4.3 Analysis and Reporting

To provide the basis for evaluating project performance, the data collected as part of the above-described monitoring efforts would be compiled and analyzed. The analysis would use the performance criteria to evaluate whether the mitigation measures are achieving restoration success. The results of the analysis would be presented in a report; a report would be produced annually for each year that monitoring is conducted (see Section 4.5 for a discussion of the monitoring schedule). After the final year of monitoring, assuming the performance criteria have been met, the project sponsors would be responsible for preparing a close-out report.

In the event that the evaluation indicates that the project has not met the performance criteria, the project sponsors would consider implementation of adaptive management actions as needed to attain the ecosystem objectives for the project. Considerations for the adaptive management approach are discussed below.

4.4 Adaptive Management

Adaptive management is a structured process of learning and using newly-acquired knowledge to adjust and improve project implementation. The adaptive management process promotes flexible decision-making as outcomes from management actions are better understood. This approach helps to reduce the risk of not achieving ecosystem restoration goals. Implementation guidance for WRDA 2007 specifies that an adaptive management plan should be developed for all ecosystem restoration projects. Specifically, the information generated by the performance monitoring, as described above should be used by the project sponsors to guide decisions relative to operational or structural changes that may be needed to ensure that the ecosystem restoration project meets the success criteria. This decision-making process may depend on a number of variables, including the timing and/or spatial scale of the performance issue, the urgency with which the issue must be addressed, and/or the type of adjustment that is needed to respond to the issue. The guidance specifies that if an adjustment is anticipated due to high uncertainty in achieving the desired outputs/results, the nature and cost of such actions should be explicitly described as part of the decision document and expressed in each of the monitoring reports as they are performed.

To evaluate the adaptive management measures that may be required for the proposed project, the potential risk and uncertainty relative to achieving the performance standards was assessed and potential adaptive management measures were identified. Specific measures that were considered included changes to project-related conditions, as well as external factors. As part of the assessment, the extent to which these adaptive management measures could address the potential deficiencies was considered.

In general, this assessment concluded that there is little risk that the structural components of the mitigation actions would require modification, such that the adaptive management does not need to account for physical changes to the in-stream structures. Similar efforts to eliminate passage barriers have been conducted on Oahu with high levels of success, and the proposed mitigation design would build upon these efforts. Structural repairs to address erosion and/or settlement that might occur over time would be covered as part of standard O&M. In terms of achieving the performance standards, the primary risk that was identified is associated with increased abundance and predation by non-native aquatic species. As previously described, prevalence of non-native species is not currently believed to be a key limiting factor for native aquatic species in the Ala Wai Watershed (given the overall habitat conditions); however, to the extent that the monitoring results indicate that this may be the case in the future, the adaptive management approach for the project incorporates non-native species removal. It is assumed that this effort would be similar to those previously conducted by the State of Hawaii DAR staff (assumed to cost approximately $30,000); any adaptive management costs incurred during the monitoring period would be cost-shared with the non-federal sponsor.

4.5 Monitoring Schedule

The implementation guidance for Section 2039 of WRDA 2007 specifies that monitoring would be initiated upon completion of construction, and should continue until ecological success has been documented; the law allows for but does not require a 10-year cost-shared monitoring plan. If monitoring is required beyond the 10-year period, it would be the responsibility of the non-federal sponsor. Based on the nature of the proposed mitigation measures, it is assumed that monitoring would be conducted annually over a 5-year period, which would start upon completion of construction.[4] The exact timing of monitoring would be determined in the final design phase.

4.6 Responsibilities and Cost

Consistent with the requirements of WRDA 2007, the cost of monitoring would be included as part of the total project costs and be cost-shared, with 65 percent of the costs paid by USACE and the other 35 percent paid by the State of Hawaii, as the non-federal sponsor. The estimated cost for the proposed monitoring activities is summarized in Table 11. Any additional post-construction monitoring past the designated monitoring period would be entirely the responsibility of the non-federal sponsor. As the non-federal sponsor, the State of Hawaii would also be responsible for O&M activities for the mitigation measures implemented as part of the tentatively selected plan.

TABLE 11
Estimated Monitoring Costs

Parameter	Estimated Level of Effort (Per Monitoring Event)	Approximate Cost
Stream and fish surveys	Assumes a total of 20 person-days per monitoring event	$5,000

[4] In many cases, pre-project monitoring is conducted, as needed to establish the basis for measuring restoration success. It is assumed that a single pre-monitoring event would be conducted prior to construction.

TABLE 11
Estimated Monitoring Costs

Parameter	Estimated Level of Effort (Per Monitoring Event)	Approximate Cost
Data processing	Assumes a total of 5 person-days per monitoring event	$1,250
Analysis and reporting	Assumes a total of 10 person-days per monitoring event; assumes $500 in expenses per monitoring event	$3,000
Total (per monitoring event)		**$9,250**
Project Total (assuming 5 monitoring events)		**$46,250**

NOTE: Assumes $250 in labor charges per person-day.

References

USACE (U.S. Army Corps of Engineers). 2000. "Planning Guidance Notebook." Engineer Regulation 1105-2-100. April 22.

USACE (U.S. Army Corps of Engineers). 2009. *Implementation Guidance for Section 2039 of the Water Resources Development Act of 2007 (WRDA 2007) - Monitoring Ecosystem Restoration*. August.

Fitzsimons, J. M. and R. T. Nishimoto. 2007. Introduction. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:1-10.

Parham, J.E. 2002. Spatial models of Hawaiian streams and stream fish habitats. Ph.D. Dissertation, Louisiana State University, Museum of Natural Science, Baton Rouge, LA. 155 p.

Kuamo'o, D. G. K., G. R. Higashi & J. E. Parham. 2007. Structure of the Division of Aquatic Resources Survey Database and use with a Geographic Information System. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis & J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 315-322.

Parham, J.E. 2008. Development of a Database Modeling Tool to Predict Aquatic Species Distributions within Hawaiian Streams. Division of Aquatic Resources, DLNR, State of Hawaii. 56 p.

USACE (U.S. Army Corps of Engineers). 2012. Environmental Operating Principles. Available online at: http://www.usace.army.mil/Missions/Environmental/EnvironmentalOperatingPrinciples.aspx

USACE (U.S. Army Corps of Engineers). 2000. "Planning Guidance Notebook." Engineer Regulation 1105-2-100. April 22.

USFWS (U.S. Fish and Wildlife Service). 1980a. Habitat as the Basis for Environmental Assessment (101 ESM). U.S. Fish and Wildlife Service, Washington, DC.

USFWS (U.S. Fish and Wildlife Service). 1980b. Habitat evaluation procedure (HEP) Manual (102 ESM). U.S. Fish and Wildlife Service, Washington, DC.

USFWS (U.S. Fish and Wildlife Service). 1981. Standards for the development of habitat suitability index models (103 ESM). U.S. Fish and Wildlife Service, Washington, DC.

Attachment 1. The Hawaiian Stream Habitat Evaluation Procedure (HSHEP) Model: Intent, Design, and Methods for Project Impact Assessment to Native Amphidromous Stream Animal Habitat

The Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model: Intent, Design, and Methods for Project Impact Assessment to Native Amphidromous Stream Animal Habitat

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Table 25: Smoothed standardized suitability for site temperature (°C) by the species that occurred in at least 36 different survey sites within the DAR Point Quadrat Surveys. Smoothed standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green... 110

Introduction:

In Hawaii, The Department of Land and Natural Resources (DLNR) is the lead agency in the state tasked with managing natural resources and the plants and animals that depend on them. In the case of Hawaiian streams, the waters that accumulate from rainfall on headwater slopes and flow downstream to the ocean provide essential habitat for Hawaii's unique freshwater flora and fauna. While the stream habitats are critical to native fish and macro-invertebrates, an open and direct link to the sea also is vital to their existence. Understanding and managing for the continuation of healthy instream habitats and suitable migratory pathways for native amphidromous stream animals is the responsibility of the Hawaii Division of Aquatic Resources (DAR), a division within the broader DLNR. Also within DLNR is the Commission on Water Resource Management (CWRM) which has the responsibility of balancing the benefits of current and future uses of water when rendering its decisions on specific water allocations. The Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model was created as a tool to support these management responsibilities. This model helps assess the impact of the stream diversions and other stream channel modifications on native stream animal habitat.

The presence of suitable habitat is considered fundamental to the sustained occurrence of an animal species. Changes to the naturally occurring habitat brought about by man's modification of the environment may have a positive or negative affect on the quantity or distribution of a species' suitable habitat. The HSHEP model is an attempt to quantify how various man-made changes affect native Hawaiian stream animals. While suitable habitat is fundamental for a species persistence and is the focus of the HSHEP model, it is not the only thing that may affect species populations. We fully realize that other factors, such as pollution, disease, or competition with introduced species may also greatly influence the observed distribution and densities of native animals, yet understanding the natural distribution of animals without the presence of these additional factors is still important. Providing managers the ability to assess change to native species habitat with respect to flow modifications, watershed development, or in channel structures is important in understanding the positive or negative implications of various actions. The HSHEP model is intended to capture the major aspects of native stream animal ecology, the typical geomorphology of Hawaiian streams, and common modifications to the environment within a single model. Additional factors outside of habitat can be modeled with the HSHEP approach, but need additional modeling steps that are best addressed on a case-by-case basis at this point.

The HSHEP model is an outgrowth of a history of collaboration among biologists at Hawaii Division of Aquatic Resources (DAR) and researchers at various universities, agencies, museums, and private companies. The collaborative effort focused on understanding the different aspects of the ecology and management of amphidromous stream animals (Fitzsimons and Nishimoto 2007). In recent years, efforts have focused on combining the information gained from the wide range of studies into an integrated model of Hawaiian streams that include the life history characteristics of amphidromous animals, island hydrology and geomorphology, and critical management issues. This report documents results of these efforts and describes the current version of the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model.

The HSHEP model follows the overall Habitat Evaluation Procedure (HEP) model concepts developed by the U.S. Fish and Wildlife Service (USFWS) to evaluate the quantity and quality of habitat available for a species of concern (USFWS 1980 a,b, USFWS 1981). In general, a Habitat Evaluation Procedure (HEP) model has several characteristics:

1. It is a habitat-based assessment method.
2. It assumes that habitat quality and quantity are related to the number of animals using a habitat over the long term.
3. It uses measurable attributes of habitat quality and quantity to create relationships between habitat suitability and animal occurrence and density.
4. It converts suitability relationships into standardized Habitat Suitability Indices (HSI) that encompass the range of observed habitat conditions.
5. The HSI values range from 0 (unsuitable habitat) to 1 (most suitable habitat).
6. It multiplies the habitat quality (value from the HSI) with the habitat quantity (area) to determine overall Habitat Units (HU) within the area of concern.

As a result of the model design, HEP impact analyses are intended to allow the user to:

1. provide defined suitability-based estimates of HU within a study area,

2. provide impact assessments of the changes of HU within the study area under different management scenarios,
3. provide objective comparable unit measures for multi-site comparisons,
4. quantify changes in HU to be annualized and comparable with other cost/benefit analyses,
5. create plots of the distribution of HU in map-based formats (GIS analyses) to address issues of habitat fragmentation or connectivity.

The HEP user manual describes a HEP model like this, "HEP is a convenient means of documenting and displaying, in standard units, the predicted effects of proposed actions." USFWS designed HEP to be a legally defensible, standardized format for impact assessment in natural resource settings (USFWS 1980 a). While HEP models have been developed and used for impact assessment nationally for hundreds of species of birds, mammals, and fish, this was the first HEP model to assess changes in stream animal habitat in Hawaii.

Traditional HEP procedures have been joined with multi-spatial modeling efforts for Hawaiian streams (Parham 2002, Kuamo'o et al. 2006, Parham 2008). The multi-spatial models address issues of scale in understanding differences in habitat availability and species distributions. For example, the presence or density of amphidromous animals is influenced by the location of the sample site within a stream. Similar habitats found near the ocean may have different species assemblages than habitats found further inland. Additionally, characteristics of different watersheds and their streams influence the observed species assemblages. For example, streams with terminal waterfalls have different species assemblages than streams without terminal waterfalls. By assessing suitability at multiple spatial scales, different aspects of amphidromous animal ecology can be more appropriately modeled (Figure 1). As a result of the combination of the HEP method with multi-scale analysis, management issues can be addressed on a site, stream segment, whole stream, or region level. The HSHEP model is intended to be useful to assess the impacts of stream channel modification, flow alteration, land use change, climate change, stream restoration, and barrier modifications.

The general purpose of this report is three fold:

1. to explain the influence of stream modifications on the distribution and habitat availability of native stream animals;
2. to describe the HSHEP model's intent, design, and application, and
3. to document the source and use of data on habitat and fish occurrence.

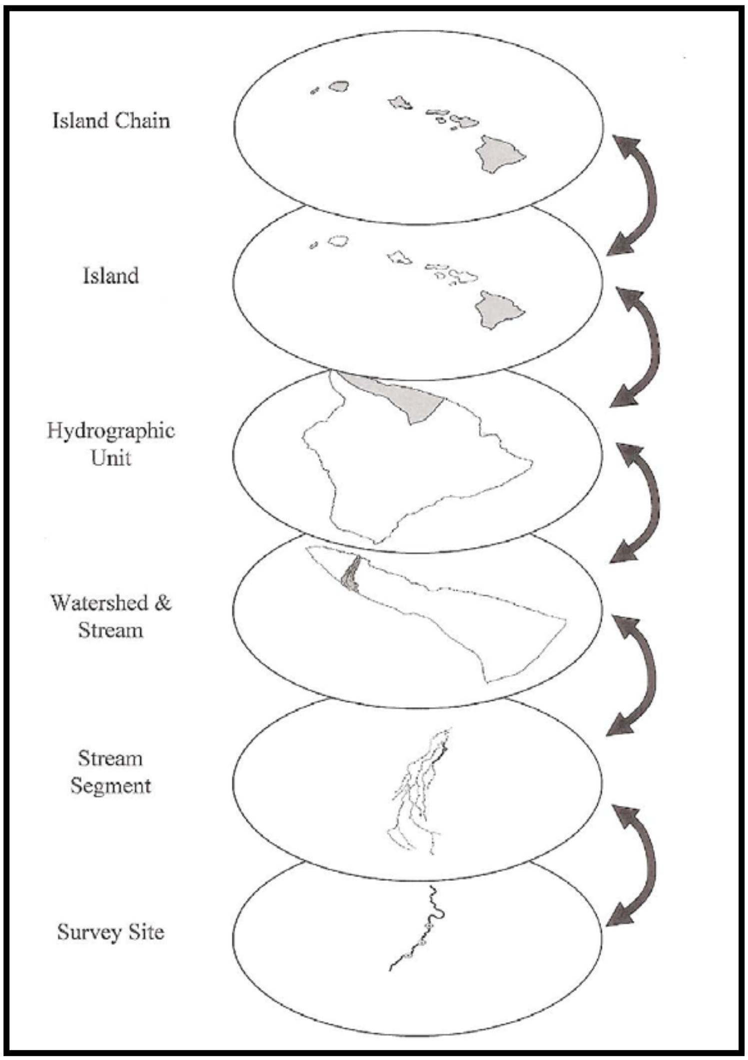

Figure 1: Spatially-nested hierarchy of the DAR Aquatic Surveys Database and predictive levels within the HSHEP model.

The Effect of Flow Diversion and Stream Channel Modifications on Native Amphidromous Stream Animals

From a management perspective, flow diversion and physical channel modifications have differing effects on the life history traits of native stream animals. While the HSHEP model attempts to capture many of the potential effects, not all can be adequately modeled at this time. Even though some of the potential issues caused by flow diversion and physical modifications are not addressed in the HSHEP model at this time, the design of the HSHEP model will allow for the inclusion of information on these issues as data become available. The following is a discussion of the potential affects that flow diversion and physical modifications may have on the different aspects of amphidromous animals' life history. The specifics regarding how the HSHEP addresses these issues are provided in the methods section.

Native amphidromous animals in Hawaiian streams share similar life history traits (McDowall 2007). In general, the animals have an oceanic larval phase during which they develop in the open ocean for up to six months. This is followed by recruitment to stream as the larvae metamorphose to postlarvae. The postlarve then migrate upstream to suitable habitat and complete their development into juvenile animals. Within the suitable stream habitat, the juveniles grow to adults and then reproduce. The newly hatched larvae drift downstream back to the ocean to undergo their oceanic larval phase. As a general model, the important phases can be separated into (1) oceanic larval phase, (2) recruitment, (3) upstream migration, (4) residence in local habitat, and (5) downstream migration and drift.

Oceanic Larval phase:

Amphidromous animal larvae living in the ocean as zooplankton during their oceanic larval phase are situated in full strength sea water (Radke et al. 1988). Whether the larvae drift widely offshore or stay near the islands in nearshore currents is unknown (Hobson et al. 2007, Murphy and Cowan 2007), but in either case there would be little or no influence of stream flow or stream habitat on this phase, and therefore no management actions related to instream structures would influence the species' oceanic larval phase.

While no direct management actions regarding flow diversion or stream channel modifications would influence the success of the oceanic larval phase, the oceanic larval phase has a role in the overall management philosophy of amphidromous animals. Murphy and Cowan (2007) discussed the possible patterns and implications of the oceanic larval phase. Although it is unknown at this time if the larvae drift passively on the ocean currents or show directed movement to stay near the islands, the larvae face many obstacles to complete their oceanic larval phase and successfully recruit to a stream. Larvae may be eaten, starve, or drift off into the open ocean. The chance for all necessary conditions lining up correctly for larvae to successfully complete this phase and recruit to suitable habitat has been likened to a winning a lottery (Sale 1978). As a result, a direct linear relationship between larvae spawned in a stream and larvae returning to a stream is highly unlikely. Given the unknowns and uncertainties associated with the oceanic larval phase, management strategies that maximize the production of larvae to the oceanic plankton pool and maximize the distribution of suitable habitat where larvae may recruit will improve the "odds of winning the recruitment lottery." While predicting the specific species, number, or time of recruitment to a specific stream may prove difficult, management actions that improve instream habitat and ultimately reproductive output are likely to result in more successful recruitment events and thus promote more stable populations among a group of streams.

In summary-

- Management actions that improve reproductive output will likely increase chances that some animals survive the oceanic larval phase.
- Management actions that improve instream habitat across a group of streams will increase the chance that suitable habitat will be encountered as the larvae end their oceanic phase and begin recruitment.

Recruitment:

There is some evidence that the freshwater plume created by stream discharge into the ocean draws recruiting animals to a stream (Nishimoto and Kuamoʻo 1997). It is theorized that larger freshwater plumes attract more recruiting animals. Amphidromous animals tend to recruit *en masse* (Nishimoto and Kuamoʻo 1997). As a result, the number of recruiting animals during a single recruitment event may not be tightly linked to the size of the freshwater plume, but the chance of the recruitment event occurring should be related to the ability of the animals to detect the stream (Figure 2 and Figure 3). In other words, if the mass of recruits is viewed as a single group or unit, the number of recruitment units that detect a stream's freshwater plume will be greater for a stream with a larger plume that occurs for a larger percentage of the time.

Figure 2: Two images of the mouth of Pi'ina'au Stream, Maui. The left image shows the amount of freshwater discharged into the ocean at low flows and the right image shows the amount of water discharged at high flows. Notice the color change in the ocean in the right image, where increased discharge (and increased sediment load) has a much larger area of influence in the ocean.

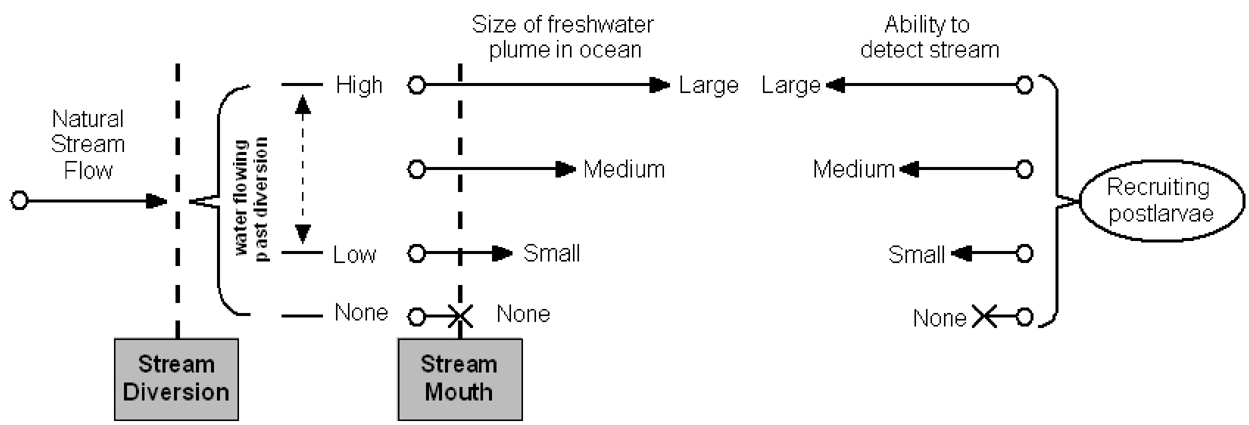

Figure 3: A conceptual model describing the role of streamflow into the ocean in attracting recruiting postlarval animals to the stream. Stream diversions decrease the size of the freshwater plume and therefore make it harder for recruiting animals to detect the freshwater from their offshore larval development areas.

In addition to the size of the freshwater plume, in many streams a stream mouth berm is created when deposition from wave action is greater than erosion by stream flow (Figure 4). The stream mouth berm acts as a barrier to recruitment. While the creation and destruction of a stream mouth berm is a natural phenomenon for many streams, decreases in stream flow as a result of stream diversion will decrease the erosive power of the stream water and increase the period of time that a berm may exist (Figure 5). Conversely, increased stream flow will decrease the amount of time that a stream remains closed by a berm and therefore blocked to recruitment. Changes in sediment quantity in the stream can also influence berm formation. Actions within the stream's watershed that increase the amount of sediment moving from the land into the stream channel likely will increase sediment deposition in stream mouths. Actions that restrict sediment input or downstream movement would likely decrease the size and thus period of time that a berm may exist.

Figure 4: Two photographs of the mouth of Kopiliÿula Stream, Maui. The image on the left shows a closed stream mouth berm and the image on the right show the berm open. Notice the

lower stream discharge on the left (i.e., more exposed rocks in stream and no white water in the upper riffle) as compared to the higher discharge on the right.

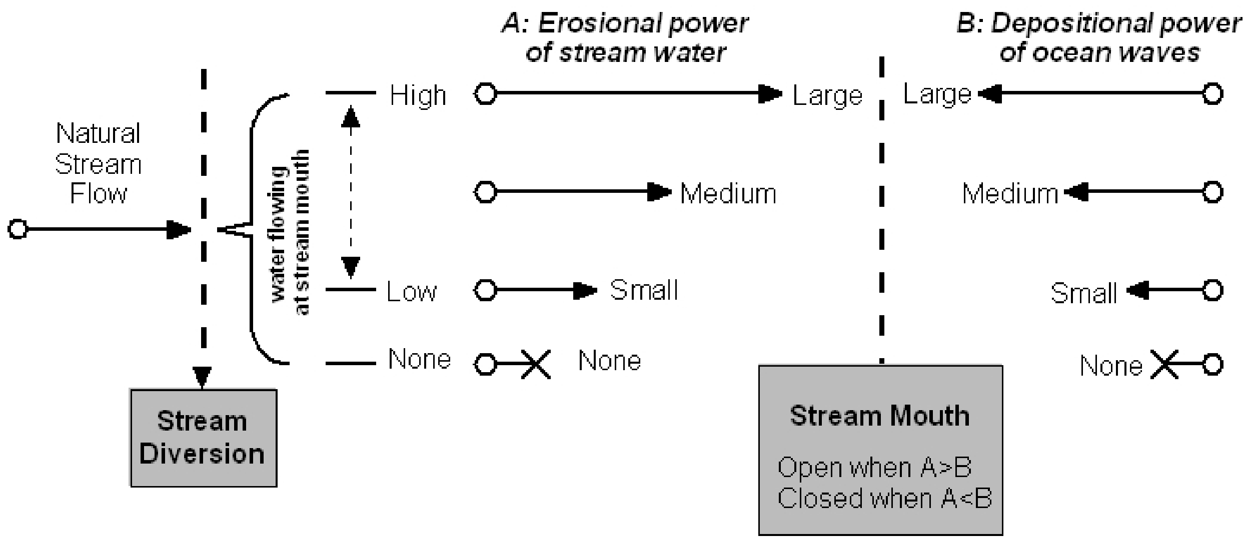

Figure 5: Conceptual model of the balance between stream power and ocean power in controlling the presence or absence of a berm at the stream mouth. When the stream mouth is open, recruiting stream animals can easily move upstream, while when a stream is closed by a berm, recruitment into the stream is highly restricted.

Management actions that increase freshwater discharge into the ocean are likely to improve recruitment by attracting more groups of recruiting animals and expanding the window of opportunity for recruits to enter an open stream mouth. Additionally, there is evidence that the presence of adult animals within a stream may draw recruiting individuals of the same species (Hobson et al. 2007). Therefore, management actions that improve adult populations in a stream may improve overall recruitment to the stream.

In summary-

- Management actions that increase the size of the freshwater plume will likely result in more recruitment events.
- Management actions that increase the time that the stream mouth is open will provide a longer window for recruitment events to occur.
- Management actions that increase instream adult population may attract more recruits.

Upstream migration:

Different species display different upstream migration capabilities (Schoenfuss and Blob 2007). Instream obstacles that prevent upstream movement for one species may be easily surmounted by different species (Figure 6). In general, differences in stream gradient or waterfalls height are measurable natural barriers to upstream migration for specific species.

Figure 6: Examples of potential natural barriers to upstream migration. Waterfalls are barriers to some species, while other species with the ability to climb may surmount the waterfall and continue moving upstream. The images show two different waterfalls in Maui streams. The left image (Honomanū Stream) shows a tall waterfall where the water is in contact with the face of the waterfall. Some species will be able to pass this type of waterfall. The right image (Honopou Stream) shows an undercut waterfall. An undercut waterfall will be a barrier to upstream migration for amphidromous species unless a wetted pathway exists for the animals to bypass the undercut.

Just as natural barriers exist in streams, some instream structures can act as barriers to upstream migration. A structure can be a physical barrier, while a stream diversion can create dry sections that prohibit movement by aquatic species, or entrain animals as they attempt to pass over the diversion structure. While the dry section is a direct result of water withdrawals, the other two factors (physical barrier or entrainment) are related to the design of the structure. As with natural barriers, species-specific differences in migratory ability influence whether or not an instream diversion structure is an actual barrier to a species.

Physical barriers that prevent the upstream migration of amphidromous animals are perhaps the most obvious barrier effect of stream diversions. Physical barriers can result from many different designs, but the major issues are height of the dam wall, inappropriate hydraulic conditions, or the creation of an overhanging drop-off in the stream channel (Figure 7 and Figure 9). Given the climbing ability of most amphidromous animals found in the middle reach to the headwaters of Hawaiian streams, as long as the height of structure is not substantially greater than natural waterfalls occurring downstream of the diversion location, then the vertical wall should have minimal impact on upstream migration. In cases where a structure is located in a relatively low gradient stream, blockage of upstream migration may be a problem.

Physical structures may also form hydraulic or behavioral barriers. If the structure creates a flow that is too fast or turbulent for animals to pass through then it can stop upstream migration. Additionally, some animals may have behavioral responses to the physical structure that prevent them from passing through the structure. For example, an animal may avoid passing through a pipe due to its darkness or its smooth sides. Currently, no studies address the hydraulic or behavioral aspects of barriers in Hawaiian streams, although preliminary studies suggest the larvae move mostly during the day and may avoid black plastic pipes (Burky et al. 1999).

In contrast to the height of the diversion, the creation of an overhanging drop-off is a problem for migrating animals wherever it is encountered in the stream. Amphidromous animals require a continuous wetted surface in order to climb an obstacle. If the water falls freely from the lip of the drop-off to the pool below then the animals cannot pass the structure (Figure 8). This situation typically occurs where a structure has been undercut by erosion on the downstream side or where a pipe is used to convey water downstream and the downstream pipe outlet is higher than the surface of the water below and extends out beyond the surface that supports it. Both of these situations can completely eliminate upstream migration, but are relatively easy to remedy by re-engineering the structure to remove the overhang.

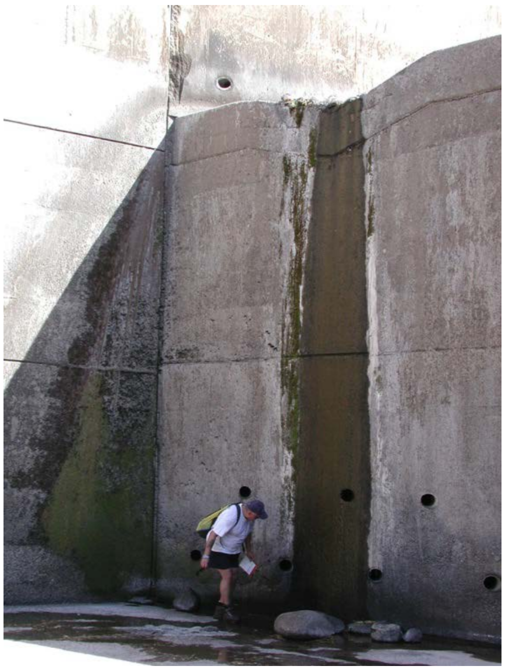

Figure 7: Vertical drop as a barrier on ‘Īao Stream, Maui (left) and a pipe providing for water flow downstream over a diversion on Hanehoi Stream, Maui. While not actual stream diversions, the images show potential obstacles that animals migrating upstream may encounter. Notice the extent of the drop in comparison to the normal channel gradient in left image. In the right set of images, it is unknown if hydraulic conditions (too swift or turbulent flow) or the unsuitable substrate (smooth pipe may prevent animals from holding on to pipe sides) would prevent upstream migration. Additional behavioral issues may also be a factor in the extent of fish passage through the pipe (fish may avoid dark areas).

Figure 8: Over hanging diversions on Honopou Stream, Maui (left) and on the middle reach of Waihe'e Stream, Maui (right). Notice how the water free falls and leaves no pathway for upstream migration.

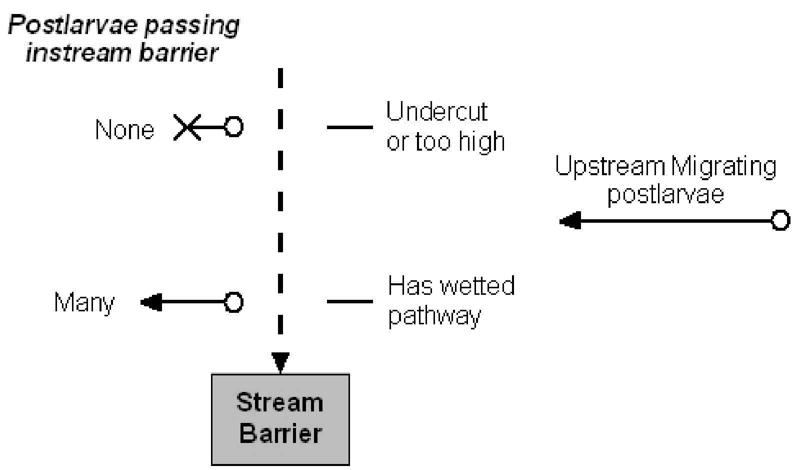

Figure 9: Conceptual model of the physical blockage of upstream migration instream structures.

Stream diversions may also result in the dewatering of a section of stream. This disruption of the physical connection between the upstream and downstream sections prevents the passage of migrating postlarvae to suitable adult habitats (Figure 11). In most native amphidromous fishes, the majority of upstream movement is accomplished prior to adulthood (Schoenfuss and Blob 2007). As the fish grow they become less capable climbers, therefore, the extent of time that a stream section is dewatered is critical to upstream migration of native stream animals. The issue of the time available for upstream movement is also important for the freshwater snail, *Neritina granosa*, as it moves slowly during migration and is susceptible to being stranded in dry sections (Hau 2007). A dewatered stream section can be viewed as a gate with respect to upstream migration (Figure 11). When water is present and flowing through the section, the section is open to upstream migration and when the stream section is dry, the section is closed to upstream migration. The following pictures show a stream bed closed and open to upstream migration as a result of stream diversion and rainfall (Figure 10). A different form of barrier may exist in channelized segments of streams. In these situations long stretches of shallow flow across open cement bottom channels can create a situation where no resting areas exist for migrating animals. Changes in flow can rapidly leave animals stranded. During sunny afternoons, water temperature can rise to very warm conditions resulting in stressful or lethal conditions for stream animals.

Figure 10: Two photographs of Kopiliʻula Stream, Maui.Both images are from stream sections downstream of the stream diversion. Notice how during periods of low stream discharge (left image) the stream pools are disconnected with dry streambed between the pools, while during periods of higher stream discharge (right image) the stream is fully connected and provides a migratory pathway for animals moving upstream.

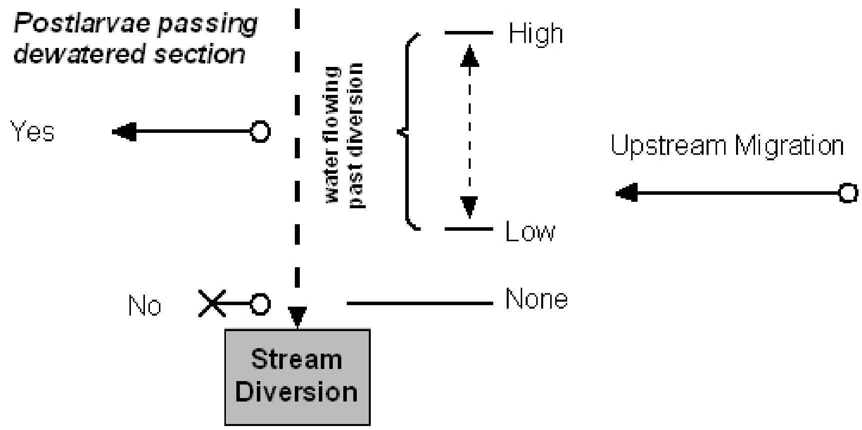

Figure 11: Conceptual model showing the probability of upstream passage by postlarvae of native amphidromous stream animals. Upstream movement would be possible when water is flowing past the diversion and provides a continuous pathway through previously dewatered stream section.

The final impact stream diversions may have on upstream migration is entrainment of individual postlarvae as they pass over the diversion structure. Depending on the design of the diversion structure, migrating animals may be entrained in the diversion and removed from the stream population (Figure 12 and Figure 13). Many diversion structures on Hawaiian streams divert water through a grate into a diversion ditch. Entrainment into the ditch would not only be possible, but likely with the typical diversion design.

Figure 12: Two images of Honopou Stream, Maui at low (left) and high (right) flows. At low flow the barrier is a complete blockage to upstream migration and at high flow most of the water flows through the diversion structure. As postlarvae move upstream through the structure, many would be entrained in the diverted waters and removed from the stream.

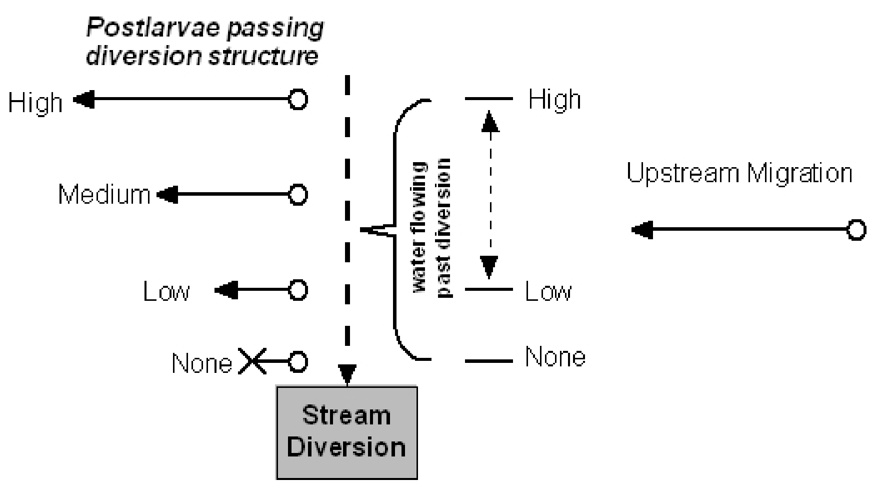

Figure 13: Conceptual model of the extent of upstream passage by postlarvae of native amphidromous stream animals. Entrainment of postlarvae would be a function of the proportion of amount of water passing the diversion and the amount flowing into the diversion.

From a management perspective, the maintenance of connectivity between the stream mouth and upstream habitats is critical for amphidromous animals. Given the vagaries of the timing of recruitment and the short developmental window for upstream movement, minimizing the time that barriers to upstream movement exist will increase the chance that suitable upstream habitat will be colonized by newly recruiting animals. The entrainment by diversion structures of migrating animals results in a direct loss of animals. After an animal has successfully survived the oceanic larval phase, found a suitable stream to recruit to, undergone substantial development changes, and moved upstream, the loss of an individual at this stage is costly to the adult population. Allowing for passage through stream diversion structures to suitable upstream habitat will likely result in greater upstream population densities of amphidromous animals.

In summary-

- Management actions that minimize barriers to upstream migration will increase settlement of juveniles in suitable upstream habitats.

- Management actions that increase the window of time that a pathway from the stream mouth upstream to suitable habitats is available will increase the chances that when a recruitment event occurs the postlarve will be able to move upstream to suitable habitats.

- Management actions that decrease entrainment of upstream migrating animals will increase the number of juveniles that settle in suitable upstream habitats.

<u>Instream habitats:</u>

Native Hawaiian stream animals move upstream to select suitable instream habitats for growth and reproduction. These habitats are typically described in terms of their physical characteristics (i.e. depth, velocities, substrates, water quality) or descriptive characteristics (i.e. riffle, run, pool). The instream habitats are influenced by the surrounding land cover and upstream conditions. From a hydraulic perspective, stream habitats observed at low discharge are created and maintained at high discharge. For example, while a stream pool is a slow, deep habitat at low discharge, at high discharge the pool is an erosional zone with swift scouring flow. A riffle is a depositional zone at high discharge and swift, shallow water at low discharge. Runs typically transport sediment over a range of discharge rates. It is important to remember that observed instream habitats are result of both high and low discharge events.

Stream diversions and other instream structures influence instream habitat in several ways. First, there is the physical structure that replaces the local instream habitat. In the case of stream diversions, this is generally a minor change to the overall stream habitat as most diversions act as a pool/riffle or pool/waterfall combination. In numerous places, native stream animals have been observed in the pool created by the diversion and in terms of total area of habitat, the stream diversion itself modifies a relatively small area. In contrast, channelized stream segments may result in the loss of habitat over the entire area they occupy. In some locations these channelized stream segments may be more than a kilometer in length. Thus the physical disruption of instream habitat by the instream structure is dependent on the size and construction of the particular structure.

In addition to the physical changes in stream habitat, stream diversions also decrease habitat area as a result of the removal of water from the downstream channel (Figure 14 and Figure 15). In the most extreme cases, the diverting of 100% of the water can result in the elimination of all habitats downstream of the diversion by dewatering the downstream sections. At lower percentages of diversion there is a decrease in wetted area, depths, and velocities (Kinzie et al. 1986). The exact relationship between the change in habitat area and discharge is controlled by the geomorphology of the site in question. Habitat models suggest that changes in wetted area are closely related to available habitat for native Hawaiian stream animals (Gingerich and Wolff 2005).

In addition to the loss of habitat area, water removal may result in a decrease of the suitability of the remaining habitat. While the amount of habitat available at low discharge levels is important, the timing and duration of these low discharge events are also important. Instream habitat is a balance between sediment transport dynamics at high and low discharge and holding a stream permanently at low discharge levels will result in a gradual change in the observed instream habitats. Lack of scouring flow generally leads to the infilling of deeper habitats and embedding of larger substrates with smaller sediment and these are not suitable characteristics of native animal habitat (Kido 2002). Lower discharge rates can also result in warmer water temperatures with the sun heating the slower, shallower water more quickly than the deeper and swifter waters. Warmer water holds less oxygen than cooler water and increases bioenergetic demands on the ecothermic stream animals.

Figure 14: Changes in instream habitat after stream diversion on Hononmanū Stream, Maui. The diversion, downstream of the surveyors, was diverting 100% of stream flow (left picture). Downstream of diversion (right picture) there is no water flow and no habitat for aquatic animals.

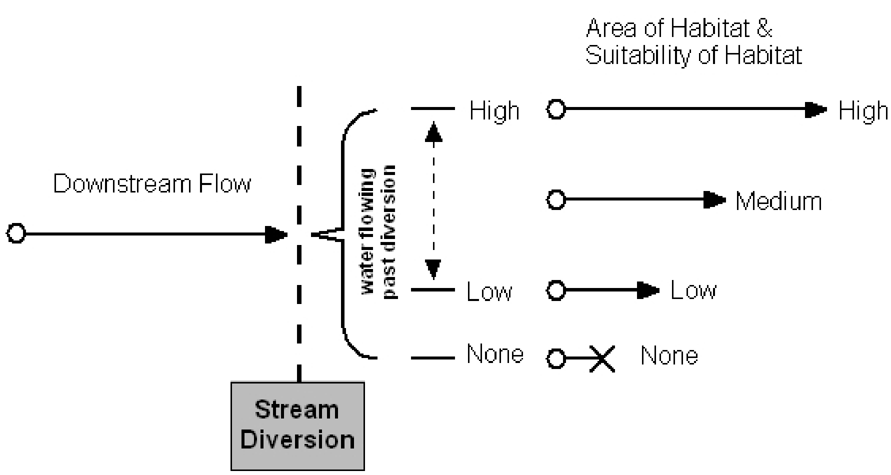

Figure 15: Conceptual model of the influence of stream diversion on instream habitat.

From a management perspective, instream habitat needs to provide adequate conditions for the animals to survive during drought conditions, provide cover to avoid predation and high flow events, supply enough food resources to grow, and provide suitable reproductive habitats. The presence of an animal in a site is not the only criteria needed to determine if the site has all characteristics necessary for the animal to complete its life cycle.

In summary-

- Management actions that provide stream discharge patterns in diverted streams that mimic natural discharge patterns with both high and low flows are likely to sustain suitable instream habitats and amphidromous animal populations.

- Management actions that avoid dewatering a streambed will provide substrate for algae (especially diatoms) and habitat for aquatic invertebrates which provide food sources for amphidromous animals

- Management actions that maintain water flow throughout the stream will minimize water quality problems, improve instream habitats, and allow movement of amphidromous animals among habitats.

- Instream structures that maintain suitable water depth in pools and runs, especially at low flows, will improve instream habitat conditions.

- Instream structures that maintain suitable water depth and appropriate substrates, especially at low flows, will provide for nest locations and assure the nests and eggs of amphidromous animals do not dry up.

<u>Downstream movement (migration and drift):</u>

Downstream movement in amphidromous animals may involve both adult and larval phases. In some species, adults may migrate from upstream locations to downstream locations to spawn (Kido and Heacock 1992, Fitzsimons et al. 2007). In all native amphidromous animals, downstream larval movement is accomplished by drifting with the stream current. The timing of the larval metamorphosis from a freshwater to saltwater larvae is measured in days and the larvae must reach saltwater to complete this transformation (Lindstrom 1998, Iguchi and Mizuno 1999, Iguchi 2007, McRae 2007). Therefore, travel time from hatching site to the ocean is critical to downstream migration of native stream animals (McRae 2007).

Similar to upstream migration issues, stream diversions and instream structures result in two separate mechanisms to prevent or reduce downstream migration and drift. Stream diversion may result in the dewatering of a section of stream. The dewatered stream section is a disruption of the physical connection of upstream sections with downstream sections preventing the passage of adults moving downstream or newly hatched larvae drifting to the ocean. Even if a stream diversion does not create a dewatered stream section, the diversion may decrease downstream water velocities as a result of the overall decrease in stream discharge. Average water velocity is a function of stream discharge and gradient. A decrease in the amount of water will result in slow stream flow velocities. As stream velocities decrease, fewer larvae can reach the ocean within an appropriate time to allow for metamorphosis into their larval phase (Figure 16) (Bell 2007). A diverted stream section can be viewed as a dial with respect to downstream drift (Figure 17). As one turns the dial upward, stream flow increases and a larger number of drifting larvae will successfully reach the ocean from their hatching sites upstream.

Figure 16: Three images of Hakalau Stream, Hawaii captured at different stream discharge rates. Notice the increased amount of swift water (i.e. white water) as stream discharge increases. The time for a drifting embryo to transit the distance of the image would decrease with increased stream discharge.

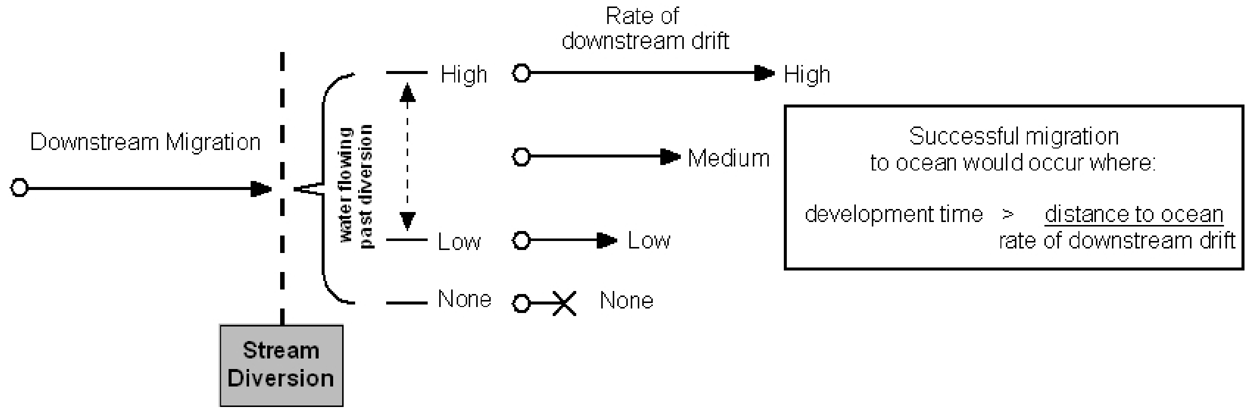

Figure 17: . Conceptual model of the influence of stream diversion on travel time and success of downstream drifting embryos reaching the ocean within a suitable development period. Successful downstream migration would be a function of rate of downstream drift and the distance to the ocean.

Stream diversions have a second effect on downstream movement. Depending on the design of the diversion structure, both adult and larval animals may be entrained in the diversion and removed from the stream population (Figure 18). Many diversion structures on Hawaiian streams divert water through a grate into a diversion ditch. Entrainment into the ditch would be possible and likely with the typical diversion design. Typical stream diversion structures divert 100% of the water at low to moderate flows. Under these conditions, 100% of downstream moving individuals would be entrained by the diversion. As stream flows overtop the diversion, a portion of the animals would likely pass the diversion and continue downstream (Figure 19).

Figure 18: Stream diversion intakes on Waiheʻe Stream (left) and Honopou Stream, Maui (right). Notice how 100% of the water flows into the diversion at the observed discharge. An animal moving downstream would be transported with the water and entrained in the diversion structure resulting in 100% mortality.

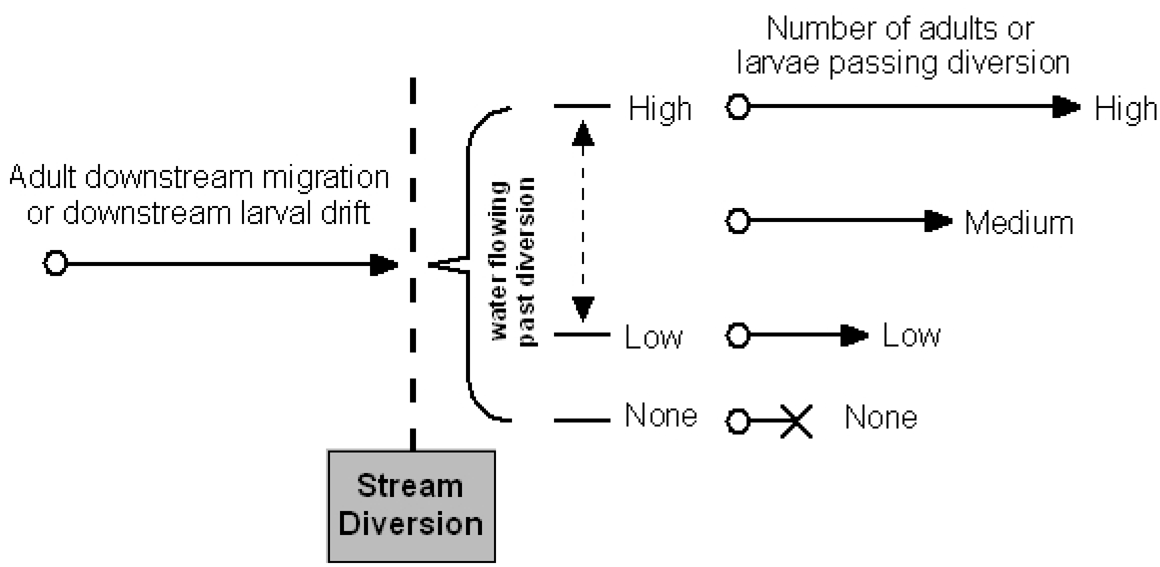

Figure 19: Conceptual model of the extent of diversion passage by downstream drifting larvae of native amphidromous stream animals. Entrainment of larvae would be related to the percent of water passing over the diversion compared to percent of water diverted.

From a management perspective, providing for adequate passage and timely transport of newly-hatched larvae to the ocean are important factors in successful downstream migration. In this respect, suitable stream habitat is more valuable if it is located near the ocean than if it is far inland or above a stream diversion site (McRae 2007). Assuring that newly hatched larval animals reach the ocean from the upstream nesting sites, coupled with successful completion of the other phases of the amphidromous animal's life history, results in ecological connectivity between ocean and stream habitats.

In summary-

- Management actions that decrease travel time from the nest site to the ocean for newly hatched larvae will increase the number of larvae that survive and successfully reach the ocean.

- Management actions that decrease entrainment of migrating adults and downstream drifting larvae will increase the number of adults that survive downstream migration to spawning sites and increase larvae that survive and successfully reach the ocean.

General Conceptual Summary

Overall, stream diversions and other instream structures interact with the native amphidromous animals found in Hawaiian stream in multiple ways. Fundamentally, aquatic animals live in the water. Diversions remove that water from the stream and instream structures remove habitat from the stream. Therefore, it is not a question of whether stream diversions and other instream structures have an impact on stream animals and their habitats, but rather of how can we minimize the impacts on native stream animals while still meeting other societal needs (such as drinking water or the minimization of flood impacts (Devick 2007)).

The following sections of this document outline the development and application of the Hawaiian Stream Habitat Evaluation Procedure (HSHEP). The HSHEP model is a standardized way to assess flow or channel modification's impact on stream animal habitat and also help prioritizes restoration opportunities that would result in the most positive benefits to stream animal populations.

Hawaiian Stream Habitat Evaluation Procedure Model:

To quantify the current conditions of the stream and to estimate the effects of the stream diversions or other stream channel modifications in the Hawaiian streams on native stream animal habitat, a specific application of the HSHEP model follows a general modeling process. This modeling process was first used for the East Maui streams (Parham et al. 2009), and further refined on Wailoa River, Kauai (Parham 2014), the Nā Wai ʻEhā Streams, Maui (Parham 2013), and Waiheʻe Stream, Oahu (Parham and Higsahi 2012 an internal DAR working project). To document the modeling process, the following sections are covered:

- general modeling process,
- selection of evaluation species,
- description of model steps,
- scenarios modeled.

General Modeling Process:

To characterize habitat availability, the HSHEP model applies a nested spatial hierarchy (Figure 1). Depending on the scenario being modeled, various levels of the hierarchy may be applied. For completed models, the site, stream segment, and stream and its watershed scales have been used in assessing project impacts. The spatial levels of island chain, island, and region have not yet been used and although the modeling design supports these spatial levels if needed, they will not be discussed further in this document.

Using the previously reported HSHEP model (Parham et al. 2009), variables at the watershed level were stream and watershed size, watershed wetness, watershed stewardship, the amount of estuary and shallow water marine habitats associated with the watershed, and the watershed land cover quality. The ratings for these variables were presented in the *Atlas of Hawaiian Watersheds & Their Aquatic Resources* (Parham et al. 2008 a,b,c,d,e) and the variables for all 430 streams included in the atlas were used to develop the model at this level. Inclusion of the watershed scale in the HSHEP model allows for comparisons of the results among streams in different watersheds.

To describe variation of instream habitat and animal distributions, variables included at the stream segment included elevation, distance inland from the ocean, and the presence of instream barriers. Native amphidromous animals are diadromous, requiring a connection between the freshwater streams and the ocean to complete their life cycle (McDowall 2007). Thus the ability of the animal to move upstream from the ocean will influence its observed distribution.

At the site level, more specific habitat characteristics are important. For the HSHEP analysis generalized suitability indices (depth, velocity, and substrate for flow studies) or (habitat type, depth, substrate, and temperature for habitat studies) are dependent on the data availability. In most cases, data is retrieved from the DAR point quadrat survey data within the DAR Aquatic Surveys Database as these surveys consistently used the same methodology to collect these habitat variables.

To compare the suitability for the stream animals, availability, utilization, and suitability criteria were developed following standardized procedures (Bovee and Cochnauer 1977). In general, this method bases habitat utilization on the presence/absence data and does not take into account site density. Habitat availability is the frequency of each habitat category and is based on the distribution of habitats observed in the field survey. Percent availability is calculated by dividing the number of observations for a habitat category by the total number of observations and multiplying by 100. Utilization is the frequency of occurrence for an individual species in each habitat category. Percent utilization is calculated by dividing the number of sites with a species observed for a habitat category by the total number of sites with a species observed and multiplying by 100. Suitability is developed by dividing the percent utilization for each habitat category with the percent availability for each habitat category. The standardized suitability has the range adjusted so that the largest value for each species equals 1 (highly suitable) and the lowest value equals 0 (unsuitable). The smoothed standardized suitability was created by averaging the value for the bin with its two nearest neighbors. In the case of the first and last bin values, they were only averaged with the single bin next to them. The smoothed suitability was used to decrease the variation between adjacent bins as a result of same size or sample distribution. Categorical suitability criteria (e.g., habitat types or substrate types) were not smoothed. See Appendix 3 for the site scale data.

By combining HSHEP model results from multiple scales, the overall model provides an assessment of habitat suitability with respect to its location in a stream and is comparable to all other streams in the Hawaiian Islands. The presence of suitable characteristics at a site is not the only important variable when determining site occupancy. A site can only be occupied by a species if that species can reach the habitat. For example, a deep stream pool with a mixture of cobble and boulder habitat may be highly suitable for a number of native species, yet if that pool is found far inland and above a high waterfall, only a few species would be expected to inhabit the pool. The HSHEP model's use of multiple spatial scales, accounts for local, network (up and downstream conditions), and watershed differences among sites.

<u>Selection of Evaluation Species:</u>

Eight species of native stream animals were selected for the purposes of quantifying habitat availability in Hawaiian Streams (Table 1). The list includes five species of fish, two species of crustaceans, and one species of mollusk. This group contains the characteristic amphidromous stream animals found in Hawaiian streams and these animals make up the majority of the native species observed during the DAR point quadrat surveys and have a substantial amount of habitat information available within the DAR Aquatics Surveys Database.

Table 1: Species habitat evaluated within the Hawaiian Streams using the HSHEP model. *Identified as "Species of Greatest Conservation Need" in the Hawaii Statewide Aquatic Wildlife Conservation Strategy (Meadows et al. 2005).

Organism Type and Family	**Scientific name**	**Hawaiian name**
Freshwater fish (family Gobiidae)	*Awaous guamensis**	‘O‘opu nākea
	*Lentipes concolor**	‘O‘opu alamo‘o
	*Stenogobius hawaiiensis**	‘O‘opu naniha
	*Sicyopterus stimpsoni**	‘O‘opu nōpili
Freshwater fish (family Eleotridae)	*Eleotris sandwicensis**	‘O‘opu akupa
Freshwater shrimp (Crustacean) (family Atyidae)	*Atyoida bisulcata**	‘Ōpae kala‘'ole
Freshwater prawn (Crustacean) (family Palaemonidae)	*Macrobrachium grandimanus**	‘Ōpae ‘oeha‘a
Freshwater snail (Mollusk) (family Neritidae)	*Neritina granosa**	Hīhīwai

The selection of the complete set of amphidromous stream animals is appropriate in this case for several reasons.

- The DAR Aquatic Surveys Database has distribution and habitat use information for each of these species.
- All of these species have a diadromous life history, meaning that they migrate from the freshwater stream to the ocean and back again (McDowall 2007). This potentially exposes the migrating animals to barriers in the stream pathway, entrainment into water diversion systems, and elimination of suitable habitat resulting from water diversions or channel modifications.
- These species are characteristic of all reaches found in Hawaiian streams. Some are found in the lower reaches, a number in the middle reaches, and some even make it to the extreme upper ends of Hawaiian streams. This allows the HSHEP model to be applied to the appropriate species within any stream segment.
- The HSHEP model has habitat suitability indices developed for each of these species.

<u>Description of HSHEP model steps:</u>

To create the HSHEP models that compare the expected current distribution and habitat suitability in Hawaiian Streams for each species independently, a series of steps is followed. It is important to understand that the HSHEP model was designed to work closely with the DAR Aquatic Surveys Database and available geospatial data. As more data are collected and stored in the DAR Aquatic Surveys Database, the underlying relationships can be updated to reflect the new information. This is also true of available geospatial data. As higher resolution digital elevation models or improved flow models become available, the data could be recalculated using this improved data set. This document describes the current version of the data used for the HSHEP model.

Changes to the model are fully appropriate when developing a model to represent a specific location and address a specific management concern. These changes to the model generally occur for two separate reasons. First, the necessary spatial levels required for an individual model varies. For example, if one compares multiple watersheds then the watershed suitability scale is required, but when the management actions are fully contained within one watershed then the application of the watershed suitability scale is unnecessary. The watershed suitability values do not change within a watershed, therefore these values will not have a variable impact within watershed results. The second type of change likely to occur is the use of specific available data to describe local conditions. For example an instream flow study would be concerned with changes in discharge and its effect on habitat while a flood control project may be more concerned with the physical changes to the stream channel. As a result the specific data required to assess a specific project may vary, but overall, the steps described below are followed for each project.

Watershed scale suitability:

1. Watershed scale metrics were created from available GIS data for variables that covered all 430 perennial streams statewide. The creation of these metrics is detailed in the *Atlas of Hawaiian Watersheds and their Aquatic Resources* (Parham et al. 2008 a,b,c,d,e and reproduced in Appendix 1). The watershed scale metrics included ratings for watershed size, wetness, stewardship, stream reach diversity, the amount of estuary and shallow nearshore marine habitat, and land cover. These metrics were intended to capture the range of the spatial variability for perennial streams in the state of Hawaii.

2. The complete set of 430 watershed suitability values was range standardized so that the range of all values had a minimum value of 0 and a maximum value of 1. This resulted in a comparable range of values for each species among the watersheds statewide.

3. For each species, the watershed scale suitability was determined by plotting the proportion of watersheds in which a species occurred against each watershed scale metric. The watersheds were grouped with the predicted results into bins from 0 to 1 by tenths, and the proportion of samples with the species of concern was determined for each group. In cases where too few samples occurred in a bin (usually fewer than 5 of the 430 samples in a single bin), the results were averaged with the nearest bin containing the fewest samples.

4. Multiple logistic regression was used to select the group of metrics that most appropriately predicted the occurrence of a species based on overall watershed characteristics.

5. The current modeled watershed scale suitability relationships are presented for each species in Appendix 1. It is important to realize that these relationships can be updated based on new collection information stored in the DAR aquatic surveys database.

6. There are several assumptions implicit in the watershed scale suitability metrics.
    a. That the set of metrics including watershed size, wetness, stewardship, stream reach diversity, the amount of estuary and shallow nearshore marine habitat, and land cover have any influence on the occurrence of native stream animals. From a general thought, the concept that larger, wetter and undisturbed watersheds with streams containing a wide variety of habitats may potentially contain a wider variety of native species is well supported in the general fisheries literature and has been observed in Hawaii. Also, the use of multiple logistic regression eliminated metrics that did not aid in predicting a species occurrence within a watershed.
    b. The relationship also assumes that there is even sampling within all watersheds. This is clearly not the case. A rating strength metric is reported within the *Atlas of Hawaiian Watersheds and their Aquatic Resources* (Parham et al. 2008 a,b,c,d,e). The rating strength metric reflects the number of surveys the type of surveys and the distribution of surveys within various stream reaches to estimate how confident we are with our underlying information. The rating strength metric is not currently used in the watershed suitability relationships but may be incorporated in subsequent versions of the HSHEP model.

<u>Instream distribution suitability:</u>

7. All native amphidromous stream animals share a common life history pattern and as a result migrate from the ocean to upstream habitats in each generation. As a result of differential climbing abilities among species, each species has its own characteristic instream distribution.

8. To account for this differential instream distribution within the HSHEP model, variables for site elevation, distance inland, and maximum downstream slope (a measure of waterfall or barrier height) are included.

9. The underlying data for these three variables comes from the USGS 10 m digital elevation model for each of the Hawaiian Islands. Digital flow models delineating watershed boundaries, stream channels, flow direction, and numerous other flow metrics were created for each Hawaiian island (Parham 2003a).

10. For each 10 m cell representing the path of the stream channel, each of the three variables was determined using ArcGIS software.

11. Elevation directly reflects the data from the underlying digital elevation model for each 10 m stream cell.

12. Distance inland is the reverse accumulation of distance against the downstream flow direction.

13. Maximum downstream slope is the reverse accumulation of the maximum change in

elevation between two adjacent cells. In some cases in specific HSHEP model applications, maximum downstream slope is replaced by actual measurements of barrier height or the extent at which a barrier is undercut from actual field measures.

14. Unlike in the watershed models, the variables used in the stream reach models were not linear; therefore, multiple logistic regressions could not be used to select the relationship between the instream distribution of the animals and the reach variables. To determine the suitability index based on the instream distribution for each species, the variables for elevation, distance inland, and downstream barrier height were combined with two different relationships and then the more appropriate relationship was selected for use. The two relationships were:

- Instream Distribution Suitability = (Elevation Suitability + Distance Inland Suitability + Downstream Barrier Height Suitability)
  where: if Elevation Suitability or Distance Inland Suitability or Downstream Barrier Height Suitability = 0, then Reach Suitability = 0

- Instream Distribution Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

15. Each relationship was range standardized with a minimum value of 0 and a maximum value of 1.

16. To select the more appropriate relationship, the results of each relationship for all sites with all data for each variable in the database were calculated. The sites were grouped with the predicted results into bins from 0 to 1 by tenths, and the proportion of samples with the species of concern was determined for each group. In cases where too few samples occurred in a bin (usually fewer than 100 of the 8300 samples in a single bin), the results were averaged with the nearest bin containing the fewest samples.

17. The results of the comparison of predicted suitability with the proportion of samples containing a species were plotted on a graph and analyzed using linear regression.

18. To select the more appropriate relationship, two criteria were used. First, the distribution of predicted results to observed proportions was visually compared. If predicted values between 0 and 1 resulted in a range of proportions between 0 and 1, the relationship was considered acceptable. If both relationships were acceptable to the first criteria, then the relationship with the higher r^2 value for the linear regression was chosen.

19. The selected instream suitability relationship for each species is shown in Appendix 2.

20. The selected relationship for each species was used to combine the three underlying source data grids within ArcGIS.

21. The instream suitability for all sites statewide was range standardized from a minimum of 0 and the maximum was 1 for each species. This resulted in a comparable range of values for each species among all stream segments statewide.

22. There are several assumptions implicit in the development of the instream distribution suitability metric:
    a. Probably the largest assumption in the instream distribution suitability metric results from the calculation of maximum downstream slope as a representation of downstream barrier height. A digital elevation model only contains a single elevation value for each 10 m cell. As a result, slope is calculated as the change between the two adjacent cells. It is impossible to tell whether the slope change is an even percent change or an abrupt drop off. To decrease this issue, if field verified data exists, it should replace the digitally derived metric. With that said, maximum downstream slope has proved effective at finding larger barriers within the stream channels throughout the state of Hawaii.
    b. Like the watershed metric, the relationships assume even sampling within all conditions. This is not true. Sampling is clearly uneven within stream reaches, but the large number of samples (8300+ for this report around the state) has helped decrease the impact of the uneven sampling effort.

<u>Combining Watershed and Instream Distribution Results:</u>

23. The resulting values for each of the relationships (watershed and stream segment suitability for each species) were appended to separate 10 m grids for each island in ArcGIS.

24. Each grid (watershed and stream segment suitability) was weighted by the r^2 value for the linear relationship developed for the species. The r^2 value was used as an estimator of the strength of the watershed or stream segment suitability model's results in predicting a species occurrence.

25. The grids for each scale were multiplied together in ArcGIS into a multi-scale habitat suitability grid.

26. The GIS layer for DAR streams was converted from vector to grid format and all non-stream cells were set to 0 and all stream cells were set to 1 in ArcGIS.

27. The multi-scale habitat suitability grid was multiplied by the stream grid to remove non-stream cells from the analysis in ArcGIS.

28. The resulting range of values for the multi-scale habitat suitability grid was again range standardized so that the minimum value for grid cells statewide was 0 and the maximum was 1 for each species.

At this point, we have combined and range-standardized the watershed and stream scale model with the stream segment scale model and have the values for habitat suitability for each 10 m cell of 430 streams statewide. For each species, the values for the habitat units range from 0 to 1 to reflect suitability. This step results in predictions of the non-locally corrected amount of suitable habitat for each species within each watershed statewide.

Adjusting the HSHEP model for local conditions:

To adjust the HSHEP model for local habitat conditions found in various segments of the stream, several different options are possible. The selection of the input data is usually dependent on two factors. The first factor is the availability and detail of site surveys and the second factor is the type of scenario being modeled. In general, site level measures will include variables such as depth, velocity, substrate, habitat type, and water temperature. There are numerous additional variables that may be useful in describing instream animal habitat, but may or may not be available for a specific project area. Traditionally, the field data used to describe local conditions comes from either point samples, small area transect samples, or possibly generalized reach scale estimates of conditions (Polhemus et al. 1992 , Parham 2003b). In all of these cases, we assume that un-surveyed areas are similar to the habitats observed in our survey areas. A newer survey technique, High Definition Stream Surveys (HDSS) may be used to document a wide range of variables for all or nearly all of the stream area under study. The HDSS approach is the preferred approach for HSHEP modeling when possible and is further described in Appendix 4.

With any of the local condition sampling approaches, the application of the information to the model is similar. The stream is segmented into areas with similar instream habitat characteristics. These segments begin or end in locations where there is a change in habitat, a barrier, or at the location of a potential modification. This results in a series of connected stream segments that are assumed to react to changes in a similar fashion. For example, we may have survey sites located in the lower, middle, and upper reaches of the stream. From the survey data, we know the distribution and average amount of various habitat types found in each reach. We then apply the results from the surveyed amounts of habitat types to the rest of the appropriate stream reaches. This, of course, assumes that our survey area is representative of the rest of the reach. As with any model, greater sampling and a wider variety of locations will result in a more accurate output. Depending on the size and importance of the project, the amount of fieldwork to characterize local habitat conditions will vary.

Specific local habitat steps:

29. From a vector (line) representation of the stream in ArcGIS, separate the stream into its appropriate segments based on reach breaks, barriers, project locations, or any other appropriate division.

30. Link a table containing average habitat characteristics to each segment.

31. Determine local habitat suitability for individual species by applying appropriate weighting factors to the description of locally available habitat. The species specific weighting factors are typically created from information contained in the DAR Aquatic Surveys Database. This database contains many thousands of samples and species observations from streams across the state of Hawaii and is considered the best source for this information.

32. Convert the stream segments (with their appropriate local habitat suitability score) into a grid of the same size and dimensions as used in the instream distribution portion of the model.

33. Multiply this local habitat suitability grid to the combined watershed and instream distribution suitability grid. This will result in a locally-corrected representation of habitat suitability for a species for each 10 m of stream. It also addresses its instream distribution and larger stream and watershed characteristics.

Scenario Models:

In general, the HSHEP model was designed to address the effects of two common instream modifications: the diversion or modification of stream flow and physical changes to the stream corridor. The impact of these two modification types can result in changes in a site's habitat suitability, changes to passage, and/or entrainment of animals during migratory events. The HSHEP model takes into account that not all actions will result in all possible impacts. Thus, the description and definition of the project impact must be clearly defined and related to available data describing local conditions.

To address specific project conditions and available local data, a graphical box model representing the modeling scenario features and their impacts is created. The following is a description of the box model process using an example from Iao Stream on Maui (Figure 20). Not all possibilities are shown in this example, but it highlights the conceptual approach well.

The box model for a stream contains the stream and its tributaries from the ocean upstream to the headwater reaches. The stream contains breaks at the various segments determined in the local habitat suitability section. It also contains representations for barriers or project modifications where appropriate. To the right of the stream representation are three additional columns. The first provides labels to each stream segment and is associated with available instream habitat. The second column describes impacts to downstream moving animals and the third column describes impacts to upstream moving animals. This box model provides a useful mechanism to track the label, type, location, and sequence for various possible scenario modifications.

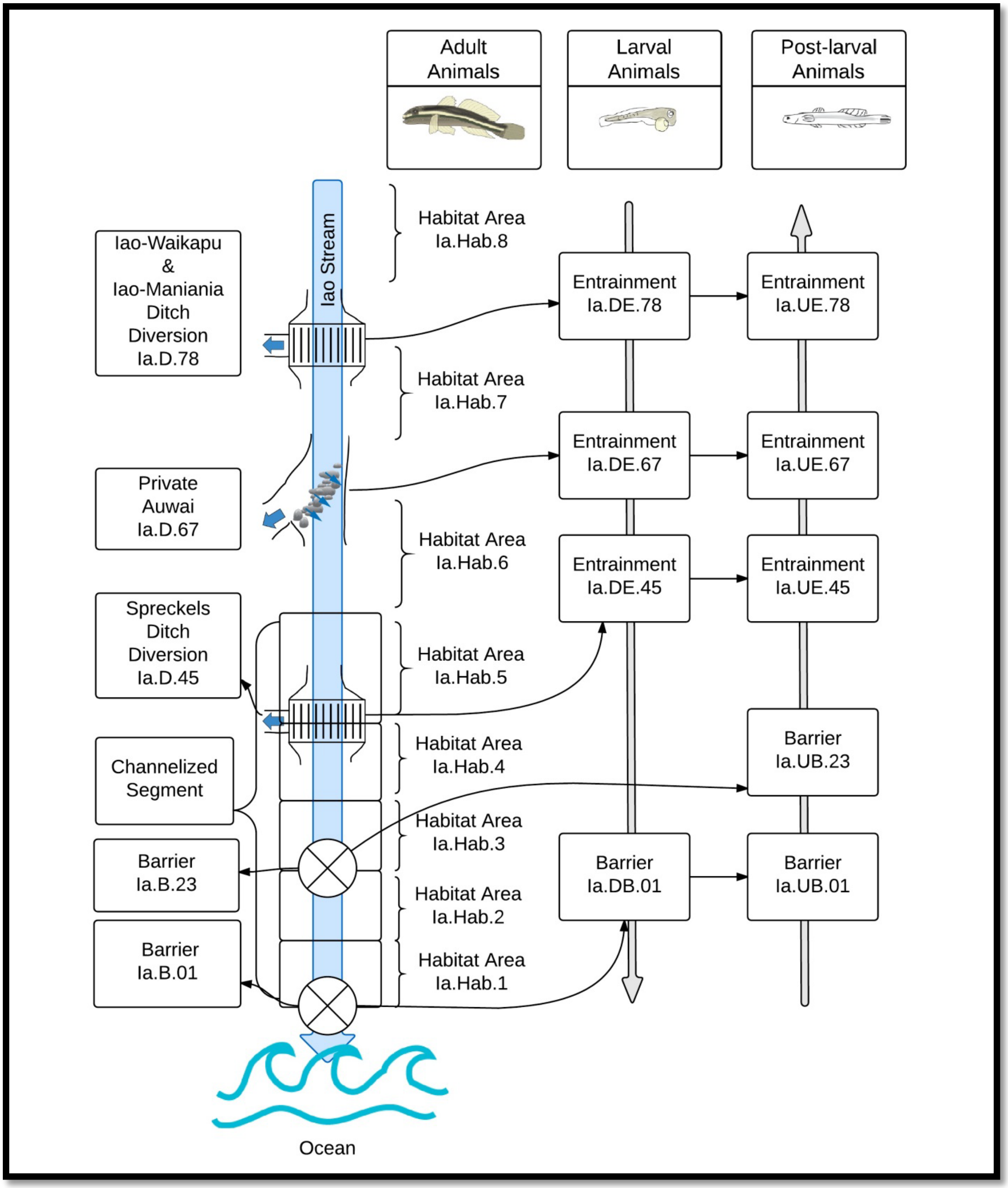

Figure 20: Example HSHEP graphic box model from Iao Stream, Maui. Box models are not to scale.

The impacts of stream diversions, barriers, and other instream modifications are estimated by describing a modification and then applying an impact factor based on the specific design criteria of the modification. In general, all of these potential modifications will share four possible impact factor criteria: (1) local habitat, (2) barrier, (3) upstream entrainment, and (4) downstream entrainment. An impact criterion can range from 0 to 1 with 0 representing the complete elimination of habitat and 1 representing no impact on habitat. In many cases, the specific modification will not influence a specific impact criterion and as a result will have that criterion set to one or no impact.

The description of the main modification types (Figure 21) are as follows:

> Side Diversion – This type of diversion removes water from the stream through a side intake structure (Figure 18). The water in natural stream channel flows downstream past the diversion and a portion is removed by the intake. These side diversions typically have a small dam to help increase the amount of water diverted. Both ditch and auwai diversion can fall into this group. Unless noted, there is no effect on instream habitat or as a barrier to upstream movement. Entrainment is directly related to the proportion of water removed by the diversion. When 100% of baseflow is diverted, the downstream entrainment is modeled at 80%. This would represent the entrainment of all animals drifting downstream in the baseflow and a portion of the animals that overtop the diversion at higher flows. At diversion rates lower than total baseflow removal, the entrainment value is a portion of baseflow (Q_{70}) remaining after the diversion compared to natural baseflow (Q_{70}), multiplied by the maximum entrainment rate. Upstream entrainment is modeled at a maximum of 50% of downstream entrainment. Upstream entrainment is lower because animals moving upstream are moving against the current and this will lead them upstream as opposed to downstream into the diversion. With that said, at high diversion rates, some animals will get entrained when moving upstream.
>
> Bottom Grate Diversion – This diversion type removes water from a grate covered channel that usually spans the stream channel bottom (Figure 18). Bottom grate diversions are usually found on larger stream diversions and are sized to remove 100% of baseflow. As with side diversions, unless noted there is no effect on instream habitat or as a barrier to upstream movement. Downstream and upstream entrainment rates are

modeled at a maximum of 80%. Upstream entrainment is higher than side diversion as upstream moving animals are easily trapped in the diversion as they try to pass over the bottom grate. At diversion rates lower than total baseflow removal, the entrainment value is a portion of baseflow (Q_{70}) remaining after the diversion, compared to natural baseflow (Q_{70}) multiplied by the maximum entrainment rate for both up and downstream entrainment.

Barriers – Barriers can be both natural (i.e. waterfalls) or man-made (i.e. dam). In a strict sense, barriers have two possible conditions, either open or closed. But when viewed over time and various flow conditions, the barrier may be open a percentage of the time. Therefore barrier impact value (% of time closed to migration) for each barrier is estimated from a combination of the barrier characteristics and flow characteristics at that site. Barriers usually have no local habitat or entrainment impact unless otherwise noted.

Undercut Barriers – Undercut barriers are considered a special type of barrier. Their impact is not correctly modeled from only height and flow conditions. Undercut barriers can transform an otherwise passable drop into a complete migratory barrier. From a modeling perspective the criteria are very similar, but the barriers impact value will be set to a much higher level than would be expected for similar non-undercut barrier.

Instream Structures - Instream structures can be anything built in the stream channel. Typical types of instream structures are those associated with flood control projects, bridges, or other development. The primary impact of these structures is to change in stream habitat. The structure may have differential impact within the project footprint as compared to above or below the project and therefore these extra regions are included where needed. An example of this is a debris basin. There may be little to no habitat where the debris trapping structure is located, while upstream the stream channel is occasionally cleared of debris. These two areas could be modeled with independent local habitat impact. Unless otherwise noted, instream structures will have no barrier or entrainment impact.

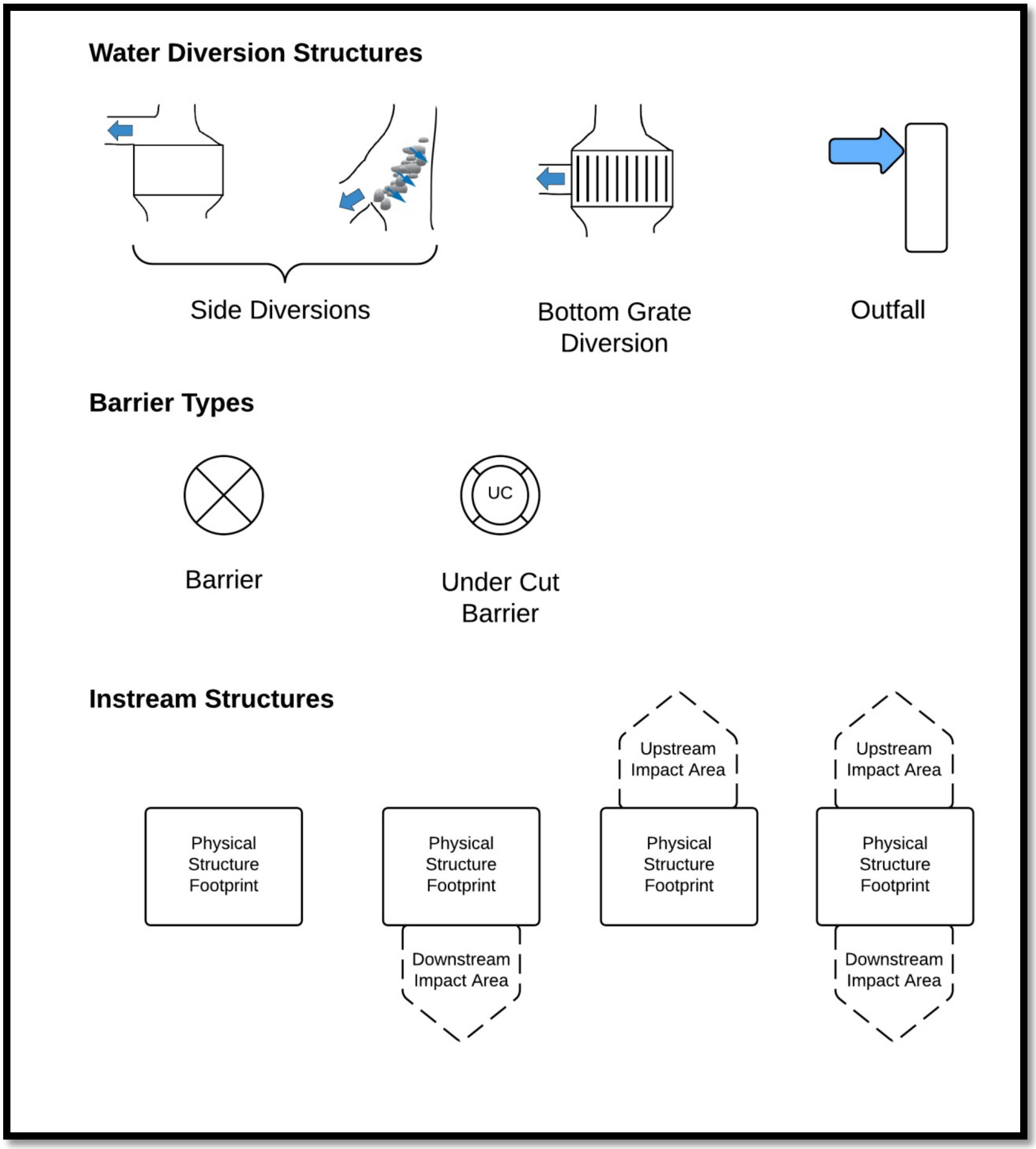

Figure 21: Modification graphics used in the HSHEP box models for each stream. Specifics used to model each type of modification would be project specific.

General Scenario Testing Steps:

34. Impact factors for the four criteria of instream habitat, barriers, downstream and upstream entrainment are determined for all potential impacted locations.
35. The barrier or entrainment impact value affects all upstream cells within the modeled stream network. For example, a barrier (A) that blocked 80% of fish passage would decrease suitable habitat in all cells above Barrier A by 80%. A second barrier (B), located upstream of Barrier A, may block an additional 50% of fish passage. Barrier B would decrease habitat suitability at sites upstream of Barrier B an additional 50%. The combination of passage impact values for both Barriers A (80%) and B (50%) would result in a total passage impact value of 90% at sites upstream of Barrier B. The inverse of the percent of fish blocked would be the percent of fish passing the barriers. In this case, 10% of fish would be expected to pass Barrier B (10% Fish pass = 20% fish pass Barrier A * 50% fish pass Barrier B).

36. If decreases in suitable habitat were the result of physical habitat modification, the estimated percent of lost habitat was multiplied with all habitat units within the affected area. This value did not impact upstream areas as described with passage impacts as it only affected the area where habitat was lost.
37. To address changes in habitat in response to changes in discharge (flow modification), the relationships between the baseflow (Q_{70}) remaining after diversion and natural baseflow (Q_{70}) typically applied. In general, the flow to habitat relationships account for changes in microhabitat variables (water depth, velocity, and substrate) with respect to changes in discharge. The microhabitat variables are weighted by their suitability to a species or species life stage, and as a result, changes in suitable habitat can be predicted from changes in discharge.
38. The amount of suitable habitat derived from the flow to habitat equations are intended to represent the average conditions for the area downstream of the diversion. There may be less available habitat immediately downstream of the diversion and more available habitat near the end of the stream segment after the stream has regained water. Therefore, the baseflow calculated at the start and end of the stream segment were averaged to provide an estimate of average baseflow within the whole segment.
39. The impacts associated with habitat loss due to water diversion (flow modification) were calculated within the specific area in which they occurred and did not impact areas up or downstream of the segment.

40. For each species in each area, the amount of habitat units lost due to changes in passage, entrainment, physical habitat modification, and flow modification were calculated. This approach allowed impacts associated with each type of impact to be considered separately as well as combined.

41. To assess the impact of the various modeled scenarios, the model was repeated with the appropriate scenario values changed.

42. Results for each scenario were created to show Habitat Units available to each species within each stream segment and the streams as a whole, as well as Habitat Units lost due to specific modifications within each scenario.

Conclusions

The HSHEP modeling approach was intended to account for the amphidromous life history strategy of native stream animals, differential instream habitat suitability, and a broad array of man-made changes to the environment. The approach is relatively straightforward yet still flexible enough to address the needs of migratory animals, changes in flow diversions, and different channel corridor construction impacts.

The strength of the HSHEP modeling approach is derived from several features. The first of these is its fundamental design which is derived from the widely used Habitat Evaluation Procedure framework. This framework allows for direct comparisons of different scenarios and supports a wide range of different impact assessments. Another strong feature of the approach is the incorporation of a multi-spatial structure. This provides the ability to differentiate local variances in habitat as well as the impact of network connectivity and watershed differences. Finally, the tight integration with the DAR Aquatic Surveys Database provides the HSHEP model a large and constantly growing source of information to better understand Hawaiian streams, available habitat, and species habitat suitability.

The HSHEP model has been used in multiple Instream Flow contested cases, in hydropower re-licensing, in barrier assessment and passage improvement, and in flood control projects. The range of projects has improved the HSHEP model as well as supported its underlying design. While the HSHEP model is specifically focused on Hawaiian streams, the underlying design should apply to oceanic islands worldwide where amphidromous and other diadromous animals are common.

Literature Cited:

Bell, K. N. I. 2007. Opportunities in stream drift: methods, goby larval types, temporal cycles, in-situ mortality estimation, and conservation implications. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 35-62.

Bovee, K. D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow. U.S. Fish and Wildlife Service Biological Service Program FWS/OBS-77/63.

Burky A.J., Benbow M.E.and C.M. Way. 1999. Amphidromous Hawaiian Gobies: Diurnal patterns of metabolism and upstream migration. Bull NABS 16(1):213. ABSTRACT

Devick, W. S. 2007. Establishment of an integrated instream flow program in Hawai'i consistent with Public Trust Doctrine. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:327-330.

Division of Aquatic Resources. 2009. Aquatic Surveys Database: http://www.hawaii.gov/dlnr/dar/streams/stream_data.htm

Fitzsimons, J.M., McRae, M.G., and Nishimoto, R.T., 2007, Behavioral ecology of indigenous stream fishes in Hawai‘i, *in* Evenhuis, N.L., and Fitzsimons, J.M., eds., Biology of Hawaiian streams and estuaries: Honolulu, Bishop Museum Bulletin in Cultural and Environmental Studies, p. 11–21.

Fitzsimons, J. M. and R. T. Nishimoto. 2007. Introduction. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:1-10.

Gingerich, S.B. and Wolff, R.H. 2005. Effects of surface-water diversions on habitat availability for native macrofauna, northeast Maui, Hawaii: U.S. Geological Survey Scientific Investigations Report 2005-5213, 93 p.

Hau, S. 2007. Hīhīwai (*Neritina granosa* Sowerby) recruitment in ‘Īao and Honomanū Streams on the Island of Maui, Hawai‘i. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:171-182.

Ford, J.I., and Kinzie, R.A., III, 1982, Life crawls upstream: Natural History, v. 91, p. 61–66.

Gingerich, S.B. 2005. Median and Low Flow Characteristics for Stream under Natural and Diverted Conditions, Northeast Maui, Hawaii: Honolulu, HI. U.S. Geological Survey Scientific Investigations Report 2004-5262, 72 p.

Higashi, G. R., and R. T. Nishimoto. 2007. The point quadrat method: a rapid assessment of Hawaiian streams. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:305-314.

Iguchi, K. 2007. Early seaward drift of gobies in Japan. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:75-86.

Iguchi, K., and N. Mizuno. 1999. Early starvation limits survival in amphidromous fishes. Journal of Fish Biology 54:705–712.

Kido, M. H., and D.E. Heacock. 1992. The spawning ecology of ‘o‘opu nakea (*Awaous stamineus*) in Wainiha River and other selected north shore Kaua‘i rivers, p. 142–157. In: W.S. Devick (ed.), New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems. Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, Hawaii Division of Aquatic Resources.

Kinzie, R.A., III, 1990, Species profiles; life histories and environmental requirements of coastal vertebrates and invertebrates, Pacific Ocean Region; Report 3, amphidromous macrofauna of island streams: Vicksburg, Miss., U.S. Army Engineer Waterways Experiment Station, Technical Report EL–89–10, 28 p.

Kinzie, R. A., III, J. Ford, A. R. Yuen, and S. J. L. Chow. 1986. Habitat modeling of Hawaiian streams. Water Resources Center Technical Report 171, University of Hawai'i, Honolulu.

Kuamo'o, D. G. K., G. R. Higashi & J. E. Parham. 2007. Structure of the Division of Aquatic Resources Survey Database and use with a Geographic Information System. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis & J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 315-322.

Lindstrom, D. P. 1998. Reproduction, early development, and larval transport dynamics of amphidromous Hawaiian gobies. Ph.D. dissertation (Zoology), University of Hawai'i. 131 pp.

McDowall, R. M. 2007. Hawaiian stream fishes: the role of amphidromy in history, ecology, and conservation biology. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:3-10.

McRae, M. G. 2007. The potential for source – sink population dynamics in Hawaii's amphidromous fishes. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:87-98.

Meadows, D., A. L. Kane, C. Mitchell, and C. Ogura. 2005. Technical Report X. Hawai‘i Statewide Aquatic Wildlife Conservation Strategy. Pacific Cooperative Studies Unit. University of Hawai‘i at Mānoa. Honolulu.

Murphy, C. A., and J. H. Cowan, Jr. 2007. Production, marine larval retention or dispersal, and recruitment of amphidromous Hawaiian gobioids: issues and implications. In: Biology of

Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:63-74.

Nishimoto, R. T., and D. G. K. Kuamo‘o. 1997. Recruitment of goby postlarvae into Hakalau Stream, Hawai‘i Island. Micronesica 30:41–49.

Parham, J.E. 2002. Spatial models of Hawaiian streams and stream fish habitats. Ph.D. Dissertation, Louisiana State University, Museum of Natural Science, Baton Rouge, LA. 155 p.

Parham, J.E. 2003a. GIS Habitat Modeling of Native Hawaiian Stream Fishes: Project Report. Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawaii.

Parham, J.E. 2003b. Hawaii Stream Type Classification Model. A GIS model that classified streams by their major geomorphological characteristics based on data from 150 Hawaiian streams. Version 1. Hawai'i Division of Aquatic Resources.

Parham, J.E. 2008. Development of a Database Modeling Tool to Predict Aquatic Species Distributions within Hawaiian Streams. Division of Aquatic Resources, DLNR, State of Hawaii. 56 p.

Parham, J.E. 2013. Quantification of the impacts of water diversions in the Nā Wai ‘Ehā streams, Maui on native stream animal habitat using the Hawaiian Stream Habitat Evaluation Procedure. A technical report submitted to Commission on Water Resource Management, State of Hawaii, Honolulu, HI. 113 p.

Parham, J.E. 2014. Assessment of the environmental impact of the Upper and Lower Waiahi Hydroelectric Plants on the native stream animals with respect to habitat changes, barriers to migration, and entrainment using the GIS model-based Hawaiian Stream Habitat Evaluation Procedure. Kaua‘i Island Utility Cooperative. 327 p.

Parham, J.E., G.R. Higashi, E.K. Lapp, D.G.K. Kuamo’o, R.T. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008a. *Atlas of Hawaiian Watersheds and* *their Aquatic Resources: Island of Kaua'i.* Bishop Museum and Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawai'i. 614 p.

Parham, J.E., G.R. Higashi, E.K. Lapp, D.G.K. Kuamo'o, R.T. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008b. *Atlas of Hawaiian Watersheds and their Aquatic Resources: Island of O'ahu.* Bishop Museum and Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawai'i. 672 p.

Parham, J.E., G.R. Higashi, E.K. Lapp, D.G.K. Kuamo'o, R.T. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008c. *Atlas of Hawaiian Watersheds and their Aquatic Resources: Island of Molokai'i.* Bishop Museum and Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawai'i. 420 p.

Parham, J.E., G.R. Higashi, E.K. Lapp, D.G.K. Kuamo'o, R.T. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008d. *Atlas of Hawaiian Watersheds and their Aquatic Resources: Island of Maui.* Bishop Museum and Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawai'i. 866 p.

Parham, J.E., G.R. Higashi, E.K. Lapp, D.G.K. Kuamo'o, R.T. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008e. *Atlas of Hawaiian Watersheds and their Aquatic Resources: Island of Hawai'i.* Bishop Museum and Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawai'i. 1,262 p.

Parham, J.E., G.R. Higashi, R.T. Nishimoto, S. Hau, D.G.K. Kuamo'o, L.K. Nishiura, T.S. Sakihara, T.E. Shimoda and T.T. Shindo. 2009. The Use of Hawaiian Stream Habitat Evaluation Procedure to Provide Biological Resource Assessment in Support of Instream Flow Standards for East Maui Streams. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 104 p.

Polhemus, D.A., Maciolek, J., and J. Ford, 1992. An ecosystem classification of inland waters for the tropical Pacific Islands: Micronesica. v. 25, p. 155–173.

Sakoda, E.T. 2007. Setting Instream Flow Standards for Hawaiian Streams – the Role of Science. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:293-304.

Sale, P.F. 1978. Coexistence of coral reef fishes – a lottery for living space. Env. Biol. Fish. Vol. 3, No. 1, pp. 85-102.

Schoenfuss, H. L., and R. W. Blob. 2007. The importance of functional morphology for fishery conservation and management: applications to Hawaiian amphidromous fishes. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:125-142.

U.S. Fish and Wildlife Service (USFWS). 1980a. Habitat as the Basis for Environmental Assessment (101 ESM). U.S. Fish and Wildlife Service, Washington, DC.

U.S. Fish and Wildlife Service (USFWS). 1980b. Habitat evaluation procedure (HEP) Manual (102 ESM). U.S. Fish and Wildlife Service, Washington, DC.

U.S. Fish and Wildlife Service (USFWS). 1981. Standards for the development of habitat suitability index models (103 ESM). U.S. Fish and Wildlife Service, Washington, DC.

Appendix 1: Watershed and Stream Scale Metrics:

The watershed and stream scale metrics are intended to capture broad differences among the watersheds observed throughout Hawaii. Differences in stream size, the amount of rainfall, land management practices, the complexity of estuary and nearshore marine conditions, and land cover can result in differential suitability for native amphidromous stream animals. To capture these differences, standardized metrics were developed for each variable.

Size Rating:

This rating compares stream size. This rating combines the standardized overall length of a stream with the standardized stream order to estimate stream size. The length and stream order were determined from the DAR Streams GIS layer. Stream order followed the Strahler stream ordering system (Strahler, 1952). This rating assumes a larger stream with more tributaries has more habitat than a smaller stream.

Wetness Rating:

This rating compares the average annual rainfall within a watershed to estimate the wetness of a watershed. Rainfall was determined from gridded rainfall layers reported in:

Giambelluca, T.W., Q. Chen, A.G. Frazier, J.P. Price, Y.-L. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delparte, 2013: Online Rainfall Atlas of Hawai‘i. *Bull. Amer. Meteor. Soc.* 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1.

The mean value for the average annual rainfall within the watershed is used for comparison with other watersheds. This rating assumes that a wetter watershed will have a larger stream with more stable flow than a drier watershed and less consistent flow.

Stewardship Rating:

Land stewardship information comes from the Hawaii Gap Analysis Program (GAP) (http://www.higap.org). Land Stewardship is not necessarily land ownership; instead, stewardship reflects who is taking care of the land.

This rating scores the stewardship categories as 1 = no biodiversity protection; 2 = protected but unmanaged; 3 = managed for multiple uses; and 4 = biodiversity protection. The percent of land in each category is multiplied by the weighting score, and the sum for the watershed is calculated. The overall sum is standardized to provide the rating.

Shallow Waters Rating:

This rating reflects the extent of estuarine and shallow marine waters associated with the stream. The estuary is the length of the stream from the coast inland to 1m elevation from the Digital Elevation Model for the Hawaiian Islands. Shallow water marine area was the distance from the stream mouth at the coast to the 60-ft contour line (10 fathoms) as digitize from bathymetric maps of the Hawaiian Islands. The length of the estuary and length from the stream mouth to the 60-ft contour line (10 fathoms) was measured and combined to estimate the amount of interaction the freshwater would have with the estuary and nearshore environments. Each category (estuary and shallow nearshore marine waters) was standardized prior to combining to weigh each category equally in the rating. This rating assumes that a stream with more associated shallow water would have greater habitat diversity than a stream that empties nearly directly into deep ocean waters.

Land Cover Rating:

Land use and land cover information was downloaded from National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (http://www.csc.noaa.gov/crs/lca/hawaii). Data from the Costal Change Analysis Program (C-CAP) were used to classify land cover. The information is based on images collected in 2000 for all islands except Hawaii where the information was collected in 2001.

In general, this rating scores the amount of forested lands positively and the amount of developed lands negatively in a watershed, and other land cover types are assumed to have a neutral association with stream quality. Specifically, the percent of land cover type within the watershed was multiplied by a value to weight the land cover type with respect to its positive or negative value associated with a high quality stream. These values are:

- Evergreen Forest: +1
- Estuarine Forested Wetland: +1
- Palustrine Forested Wetland: +1
- Estuarine Forested Wetland: +1
- Palustrine Emergent Wetland: +1

- High Intensity Developed: -4
- Low Intensity Developed: -2
- Cultivated Land: -1
- Bare Land: -1
- Grassland: 0
- Palustrine Scrub/Shrub Wetland: 0
- Scrub/Shrub: 0
- Unconsolidated Shore: 0
- Unclassified: 0
- Water: 0

The higher negative values for High Intensity Developed and Low Intensity Developed lands reflect the typical increase in pollution, sedimentation, discharge modification, and habitat degradation in comparison with streams near cultivated lands.

Watershed and stream metric combination:

To develop a relationship between a species occurrence in the various watershed and stream metrics, several comparisons were made. First, the presence or absence of a species within an individual watershed was determined from all data within the DAR Aquatic Surveys Database. This resulted in a data set of 430 watersheds (those containing perennial streams) along with each of their watershed and stream metric scores (from 1 to 10) and the presence or absence of each of the eight native amphidromous stream animals.

Next, linear regressions were used to compare the proportional occurrence of a species against each watershed and stream metric score. For each species, the watershed scale suitability was determined by plotting the proportion of watersheds in which a species occurred against each watershed scale metric. The watersheds were grouped with the predicted results into bins from 1 to 10, and the proportion of samples with the species of concern was determined for each group. In cases where too few samples occurred in a bin (fewer than 5 of the 430 samples in a single bin), the results were averaged with the nearest bin containing the fewest samples. The combination of bins usually happened at the largest size categories. For example small watersheds occur much more frequently than the largest watersheds therefore the larger size classes were grouped into one bin. Thus the metric scale does not necessarily run from 1 to 10. The intent of these species by metric comparisons was to better understand the underlying relationships associated with these metrics that may be obscured in the results of the multiple linear regression described in the following section. Figure 22 to Figure 31 display these results and show the linear relationship, P value, r^2 statistic, and confidence intervals for these relationships. Multiple logistic regression was used to select the group of watershed and stream metrics that most appropriately predicted the occurrence of a species based on overall watershed characteristics. Multiple logistic regression was used as the dependent variable is nominal (either 0 or 1) based on a species presence or absence within a watershed and there are multiple (5) independent variables. The null hypothesis in these multiple logistic regressions is that there is no relationship between a species occurrence in a watershed and any of the watershed or stream metrics. The selection of independent variables used a stepwise selection approach. An objective selection approach was used so that the results could be rerun as new data is collected and added to the DAR Aquatic Surveys Database without having to examine the data and results independently with each new run. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of a species, the predicted watershed suitability value based on the multiple logistic regression was plotted against the proportion of watersheds in which the species occurred to the overall number of watersheds within an 0.1 sized suitability bin. Figure 32 to Figure 39 show the final multiple logistic regression for each species, the test statistics, and the graphical relationship.

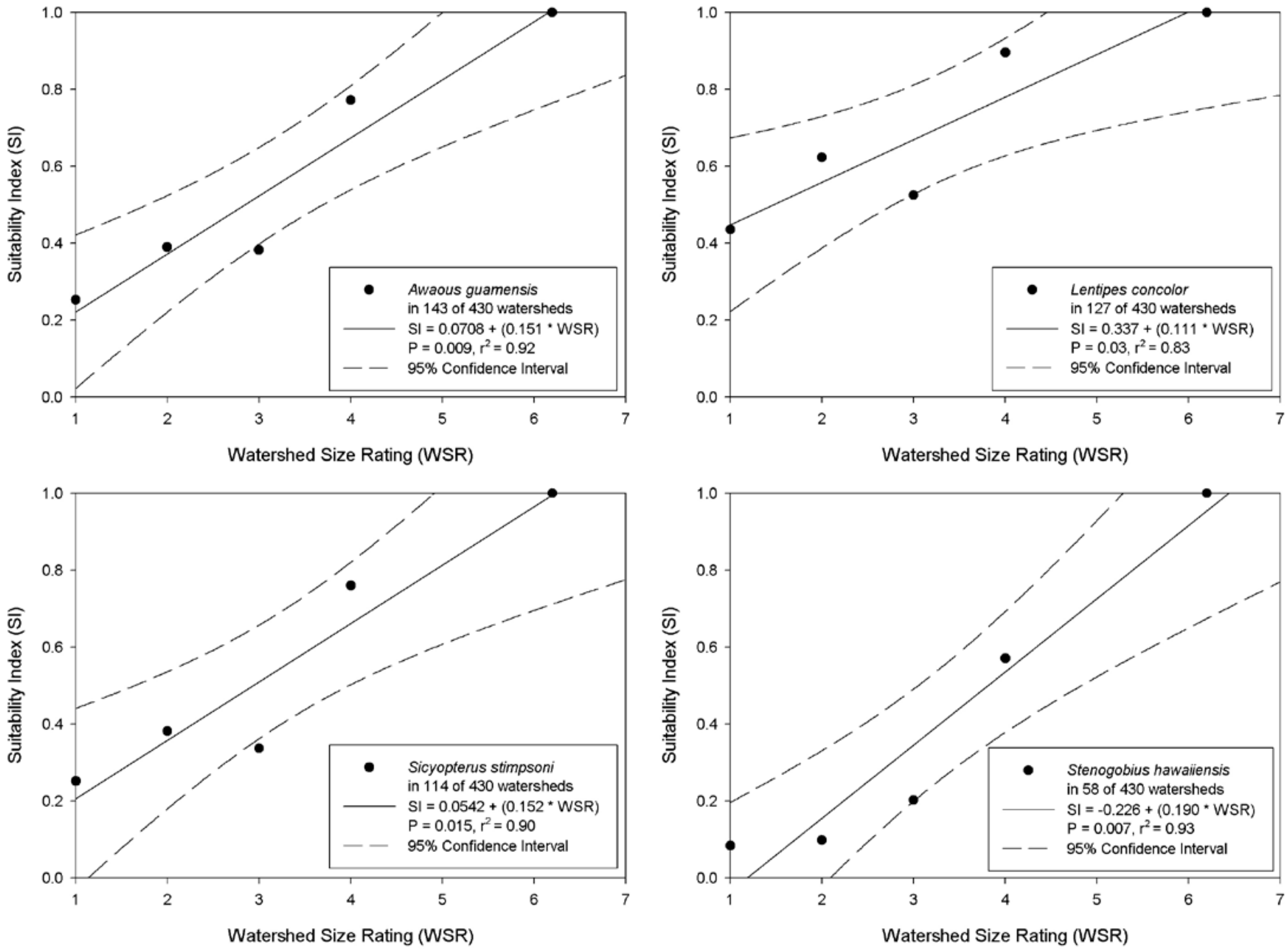

Figure 22: Suitability Indices for Watershed Size Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

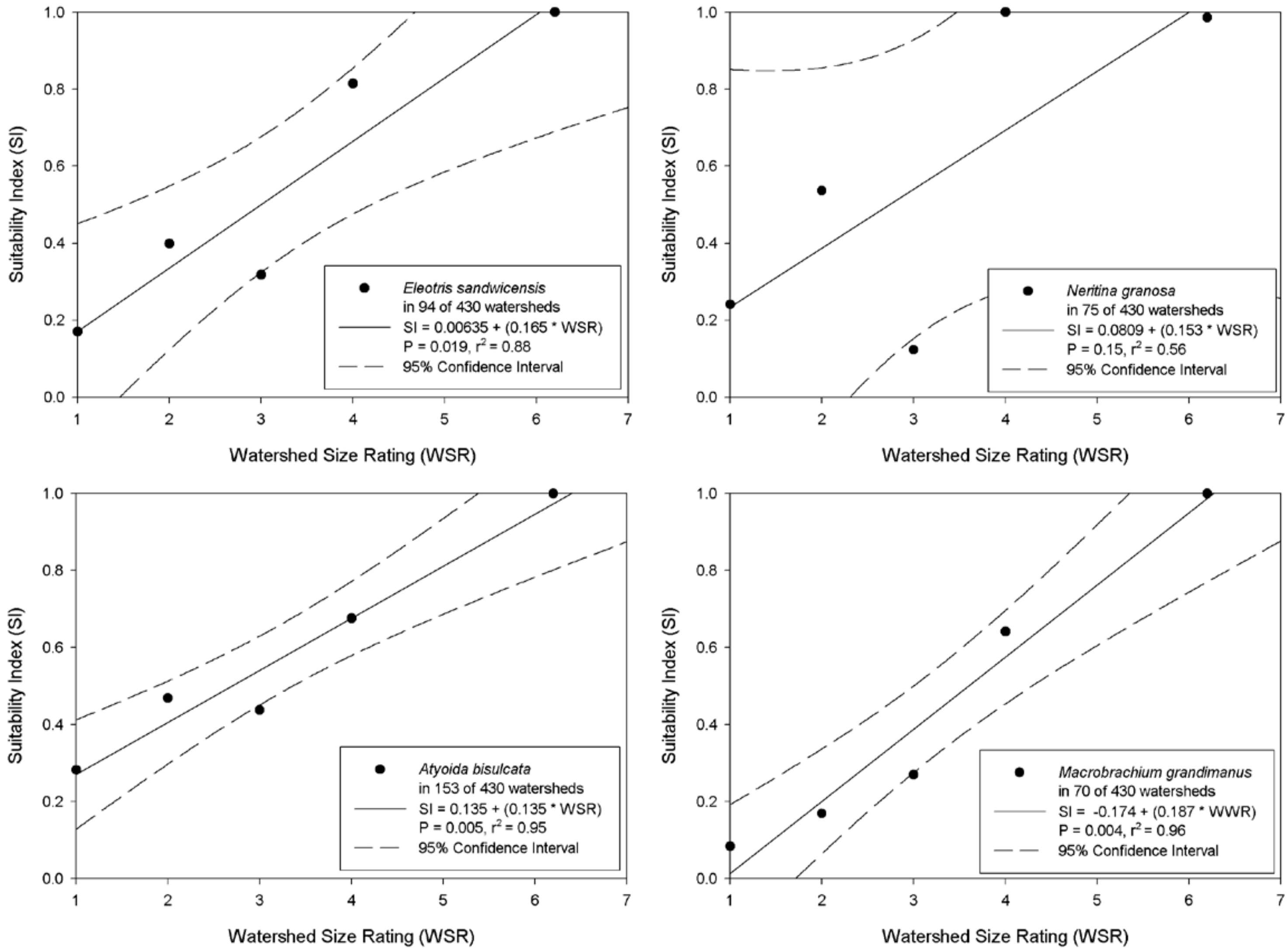

Figure 23: Suitability Indices for Watershed Size Rating for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

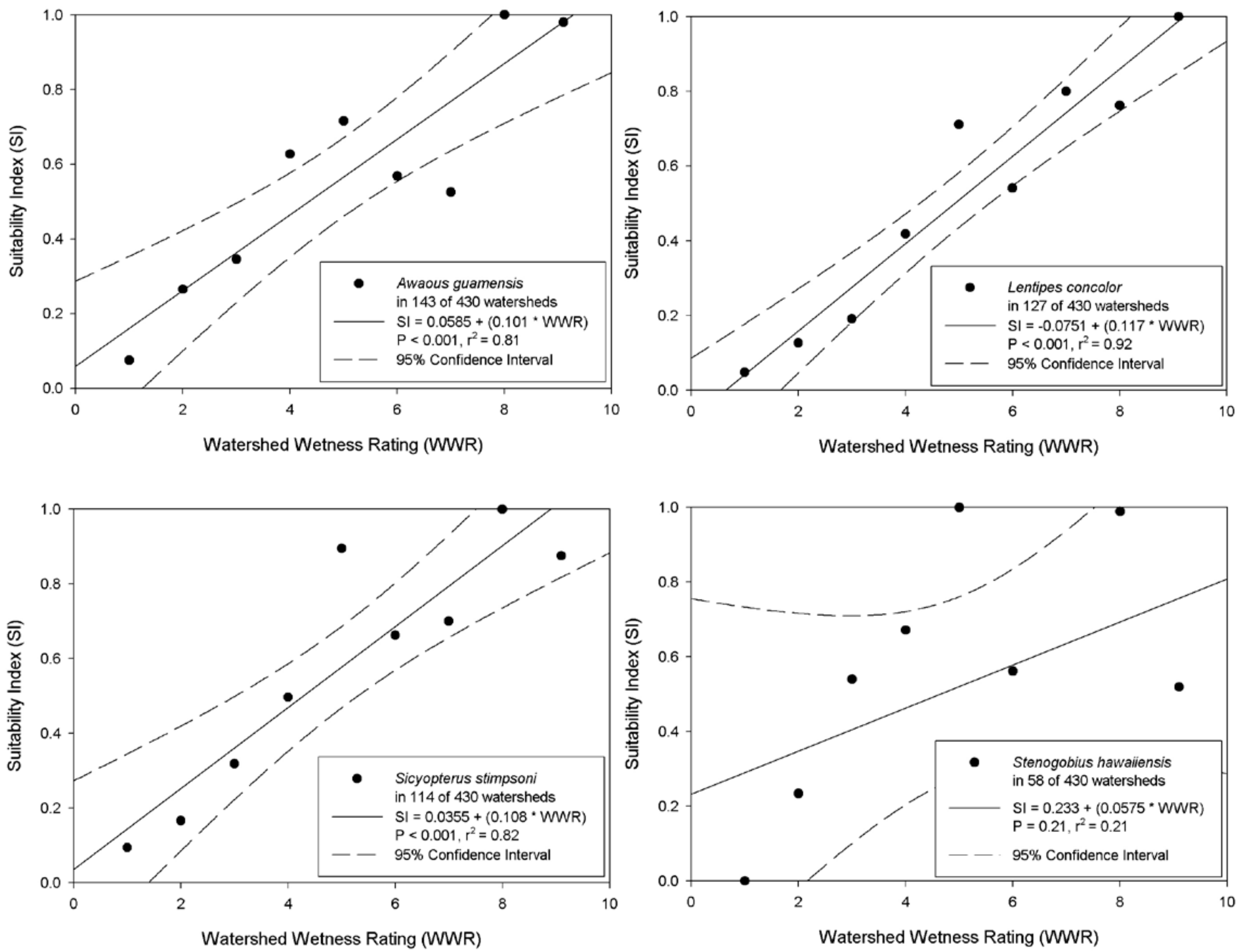

Figure 24: Suitability Indices for Watershed Wetness Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

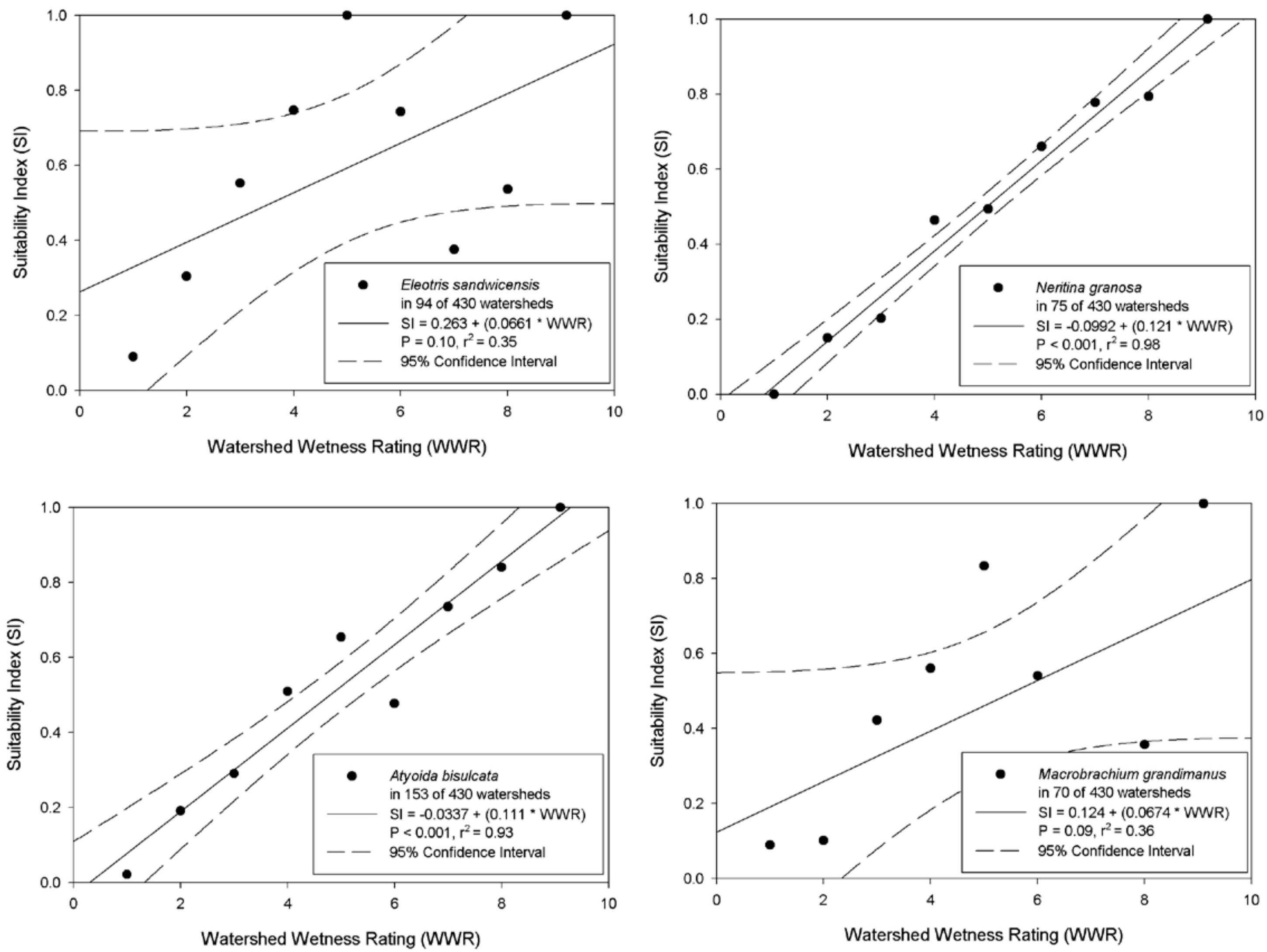

Figure 25: Suitability Indices for Watershed Wetness Rating for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

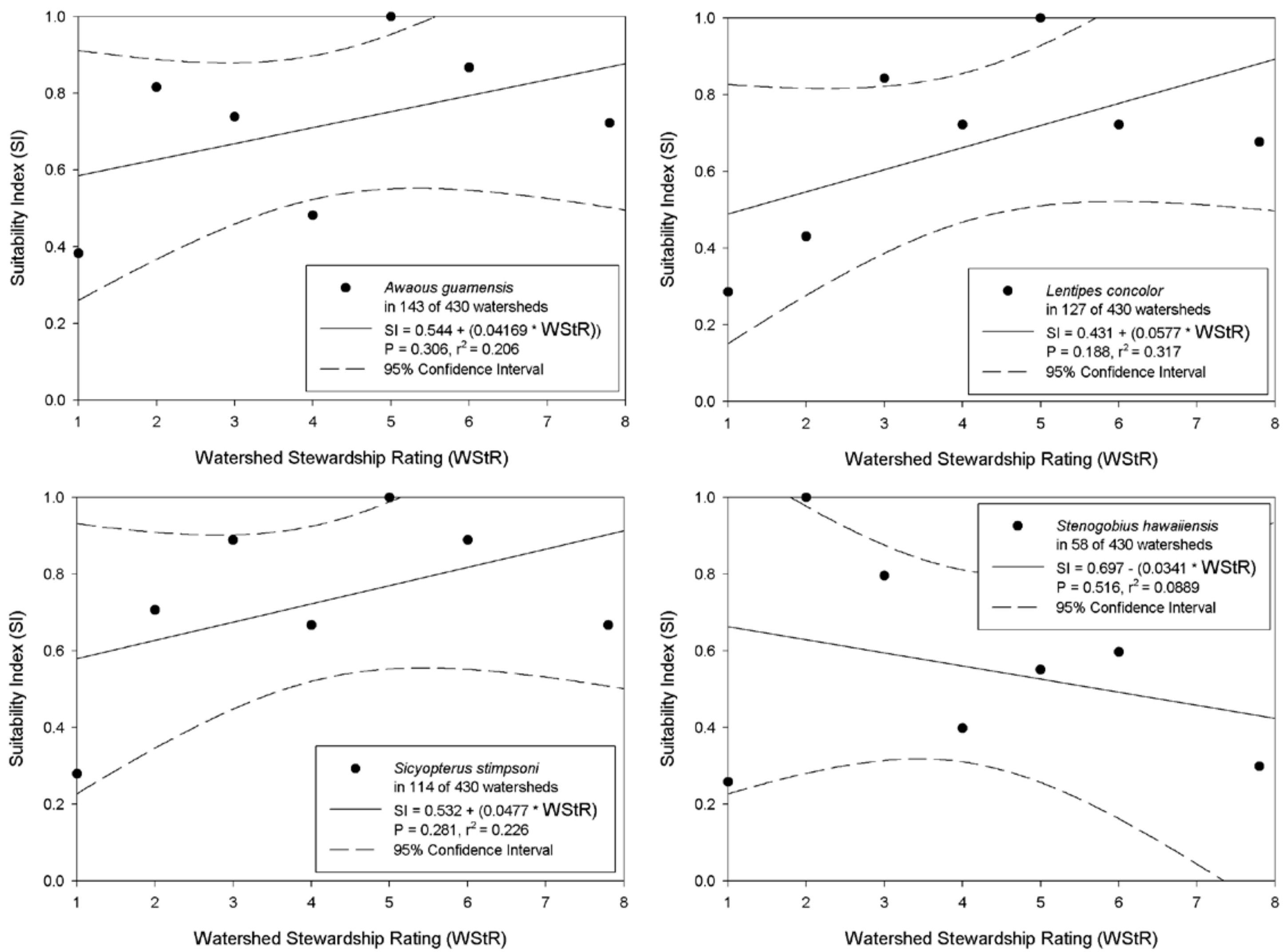

Figure 26: Suitability Indices for Watershed Stewardship Rating for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

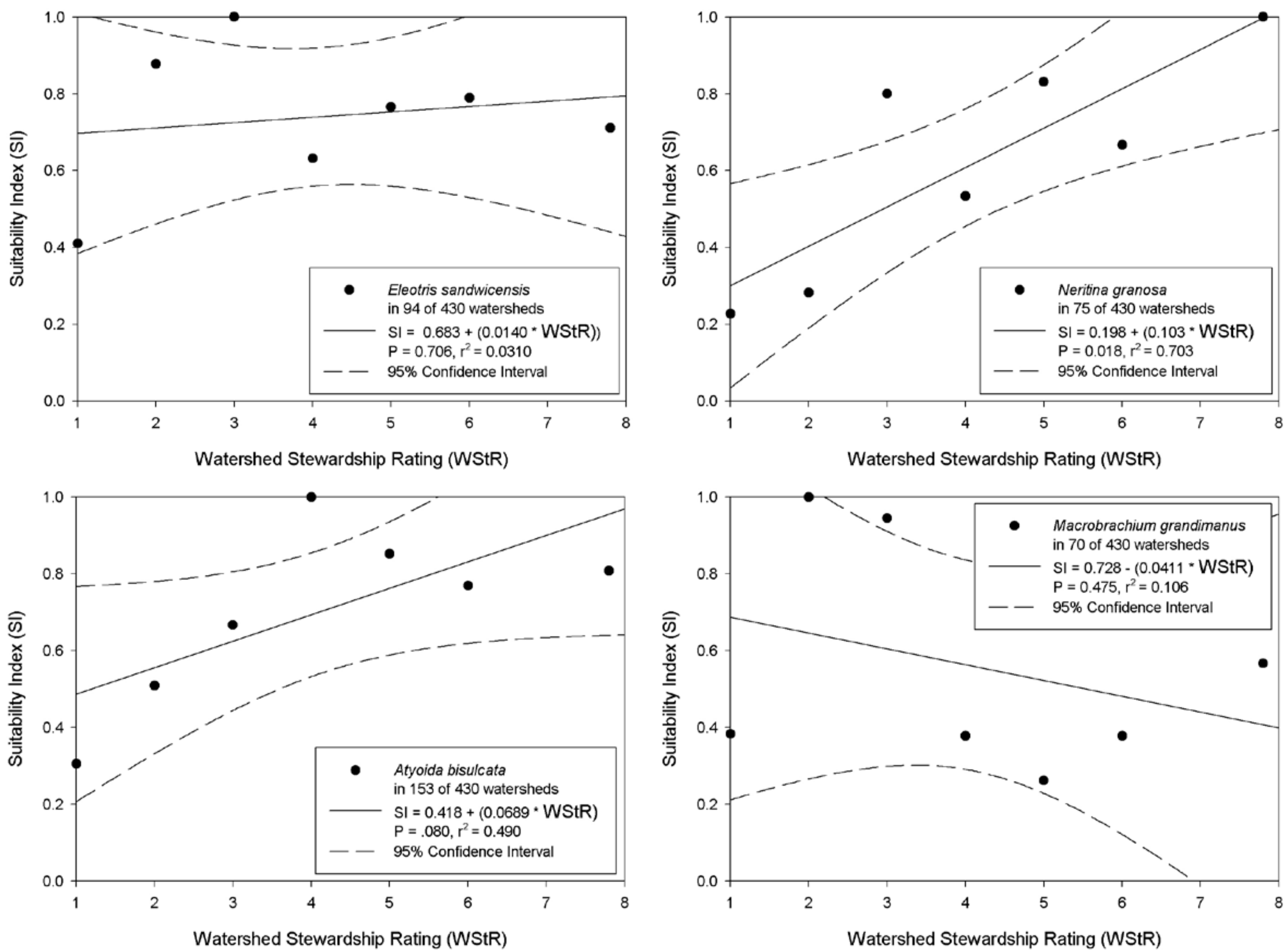

Figure 27: Suitability Indices for Watershed Stewardship Rating for *Eleotris sandwicensis, Neritina granosa*, *Atyoida bisulcata,* and *Macrobrachium grandimanus.*

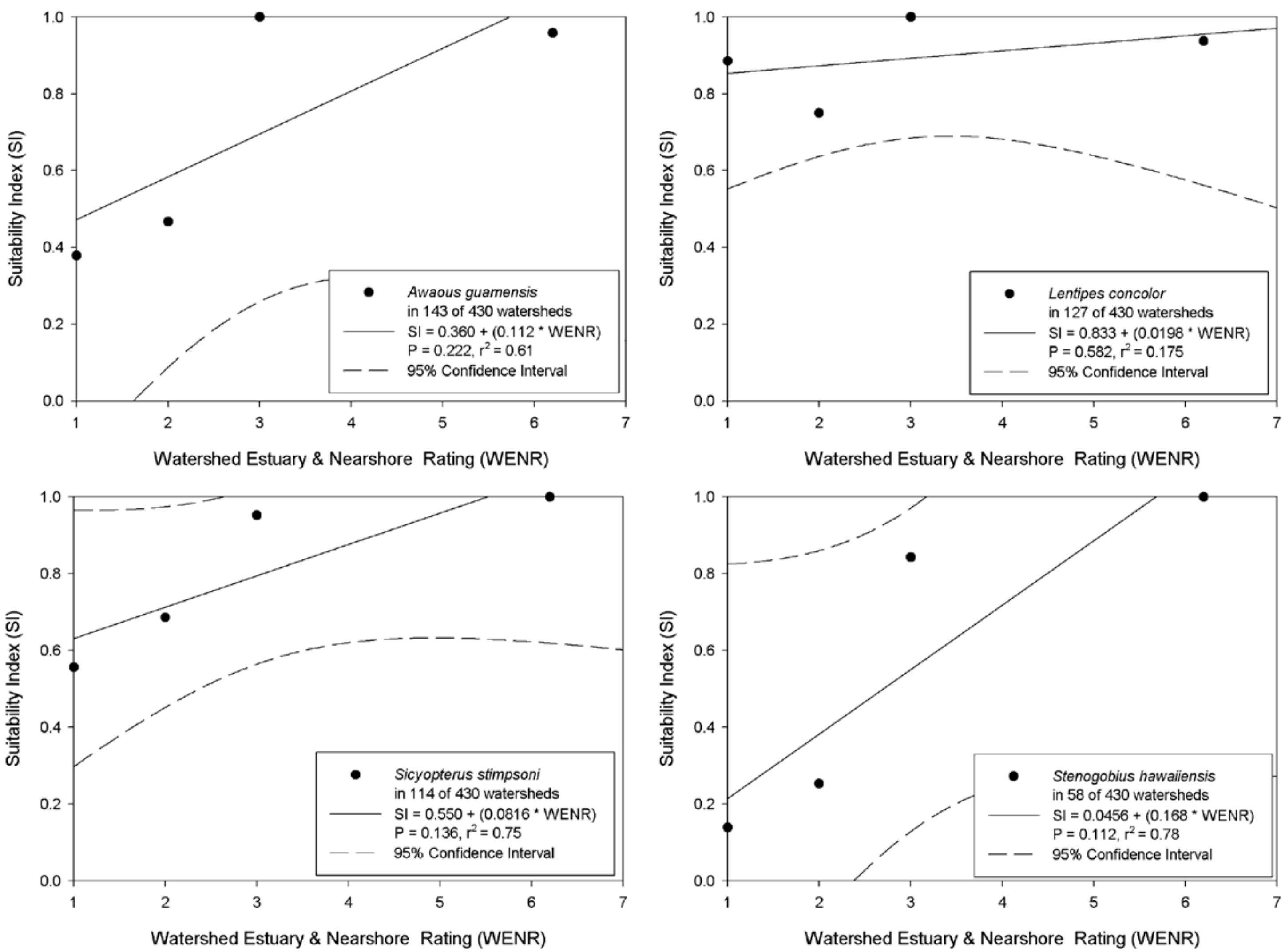

Figure 28: Suitability Indices for Watershed Estuary and Nearshore Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

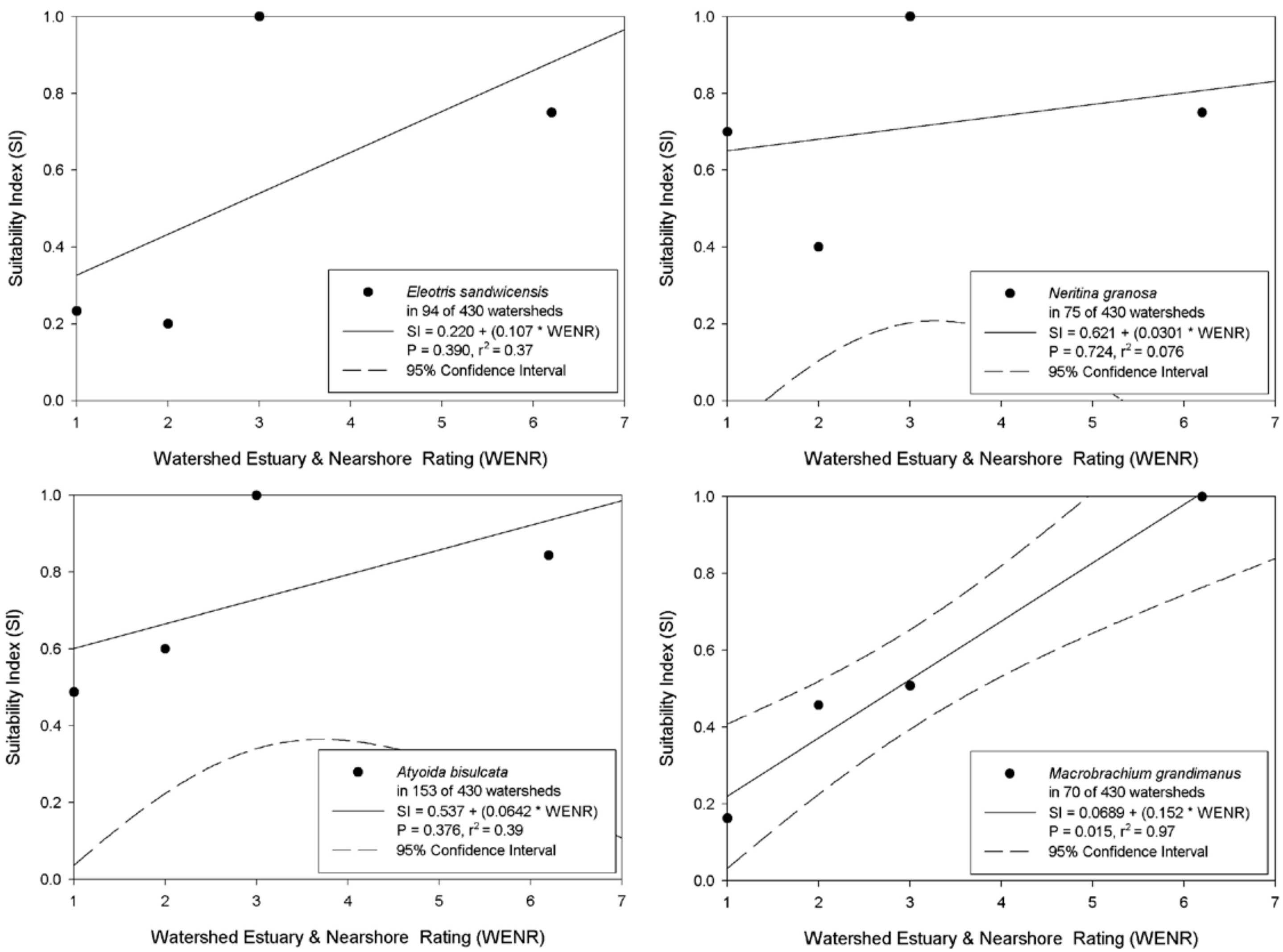

Figure 29: Suitability Indices for Watershed Estuary and Nearshore Rating for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata*, and *Macrobrachium grandimanus.*

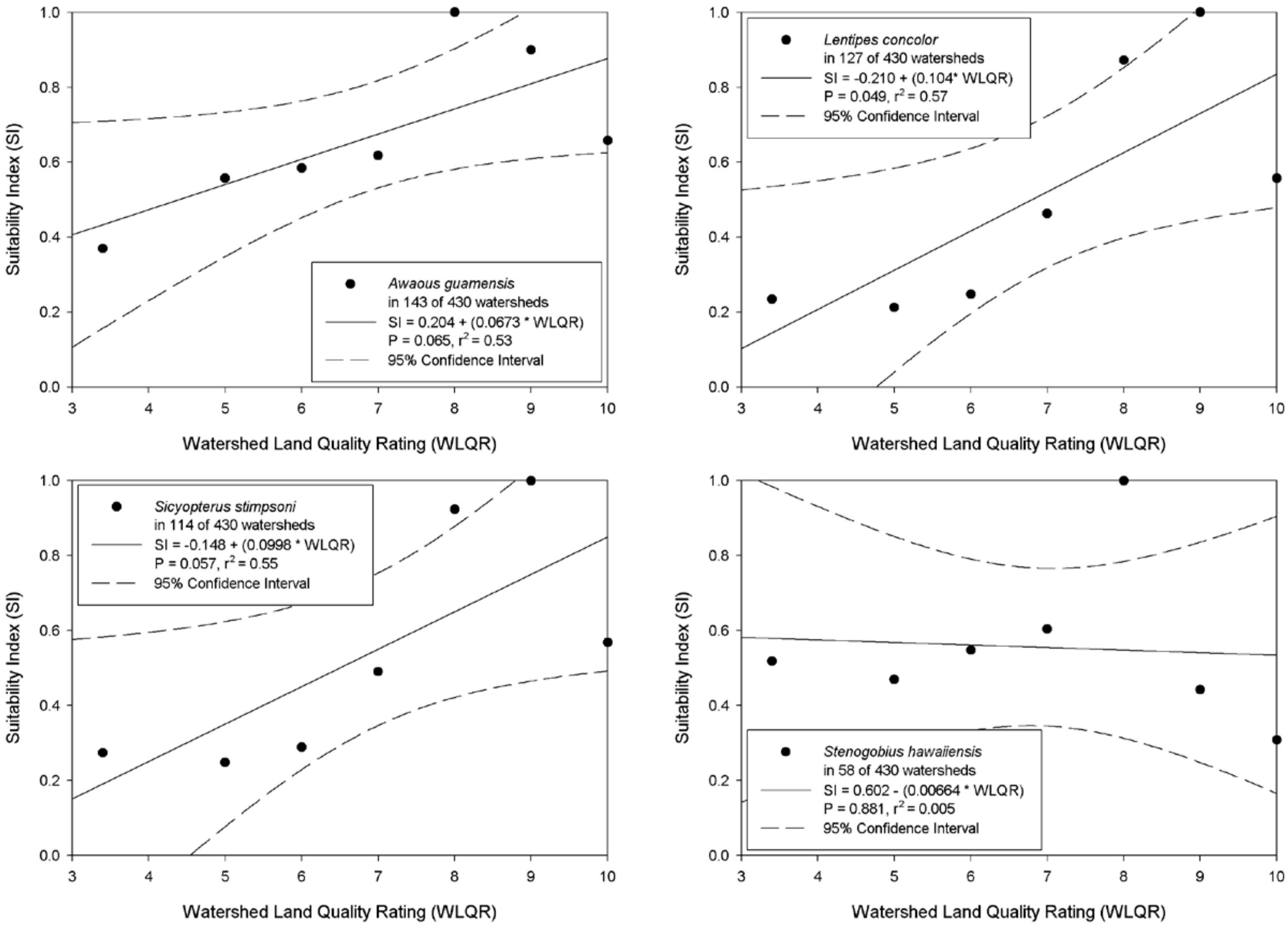

Figure 30: Suitability Indices for Watershed Land Quality Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

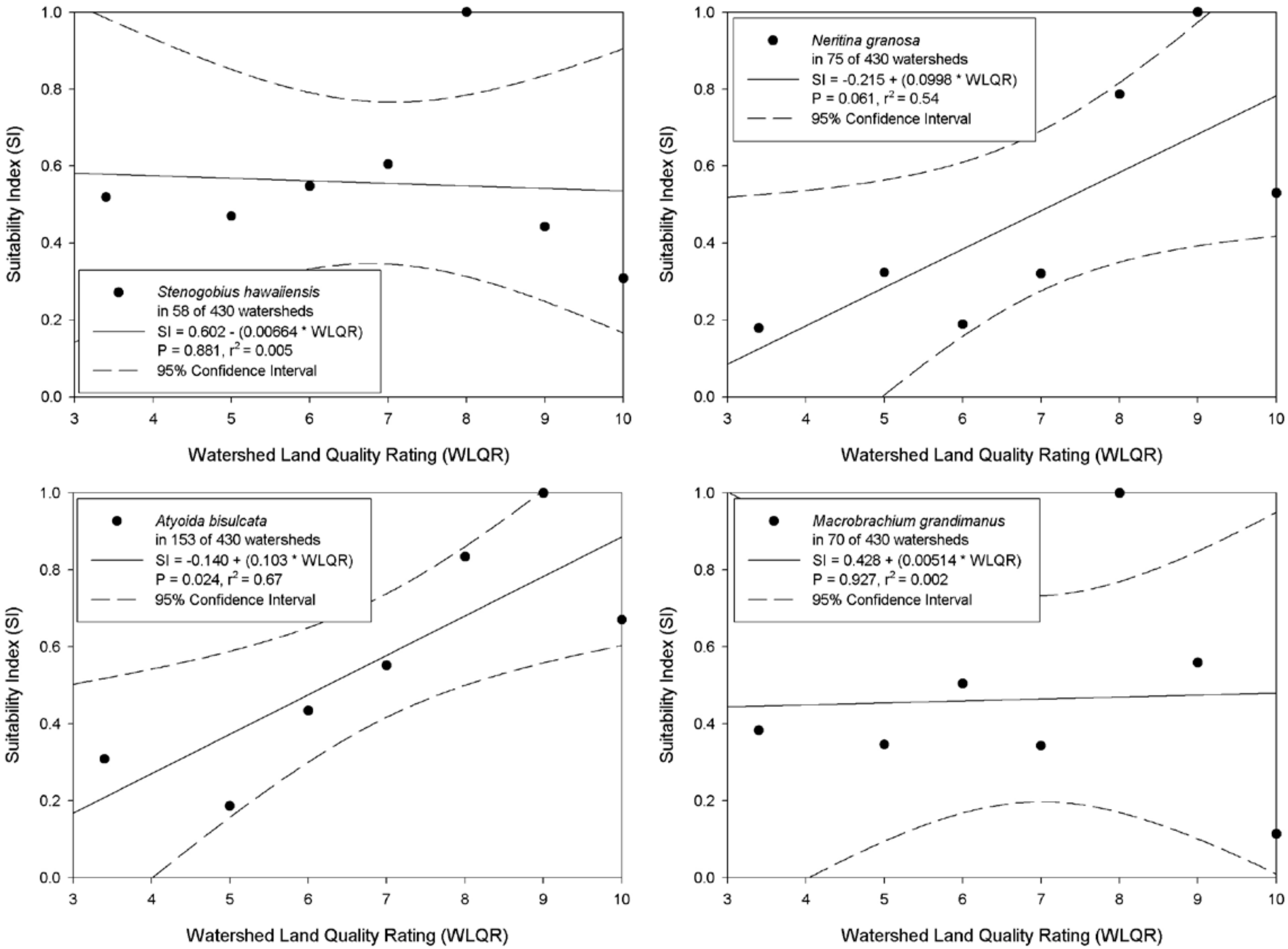

Figure 31: Suitability Indices for Watershed Land Quality Rating for *Eleotris sandwicensis, Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

Watershed Suitability Models for each species

Awaous guamensis:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.043 + (0.425 * \mathrm{WWR}) + (0.543 * \mathrm{WSR}) + (0.280 * \mathrm{WENR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)

WSR = Watershed Size Rating, ($p < 0.001$)

WENR = Watershed Estuary and Nearshore Rating, ($p < 0.001$).

This equation had a Likelihood Ratio Test Statistic of 120.7 ($P = <0.001$), and correctly predicted the presence or absence of *Awaous guamensis* in 322 of 430 watersheds (74.9 % correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Awaous guamensis*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Awaous guamensis* occurred (Figure 32).

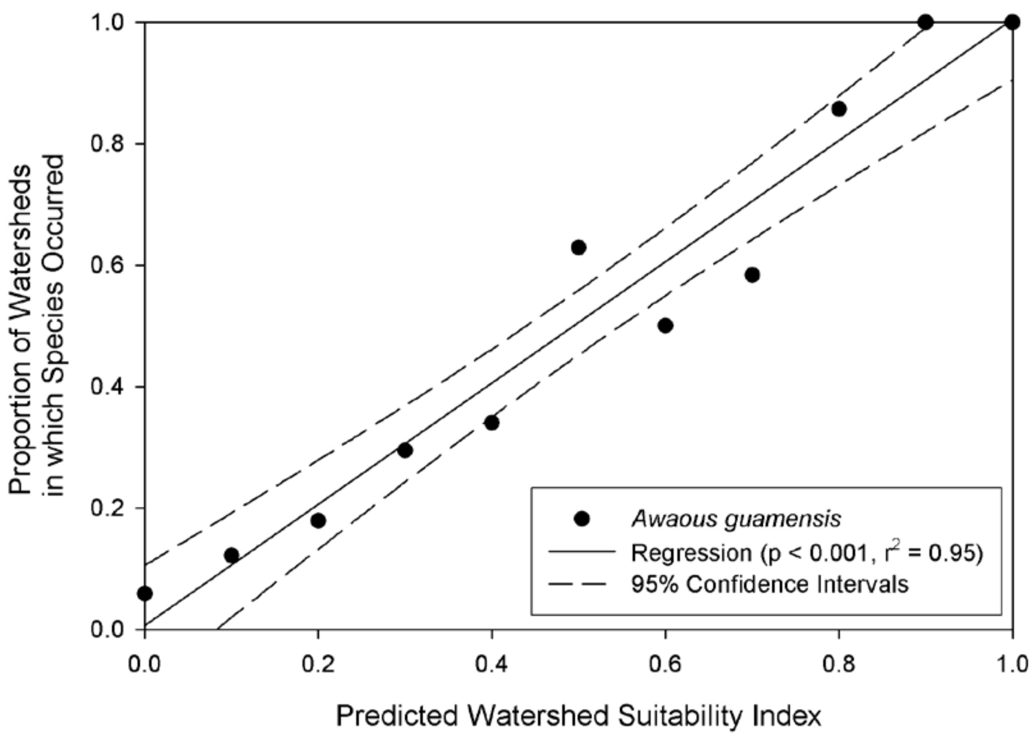

Figure 32: Proportion of the total watersheds where *Awaous guamensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Awaous guamensis*.

Lentipes concolor:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.164 + (0.493 * \mathrm{WWR}) + (0.362 * \mathrm{WSR}) + (0.121 * \mathrm{WStR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)

WSR = Watershed Size Rating, ($p < 0.001$)

WStR = Watershed Stewardship Rating, ($p = 0.025$).

This equation had a Likelihood Ratio Test Statistic of 117.8 (P = <0.001), and correctly predicted the presence or absence of *Lentipes concolor* in 322 of 430 watersheds (74.9 % correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Lentipes concolor*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Lentipes concolor* occurred (Figure 33).

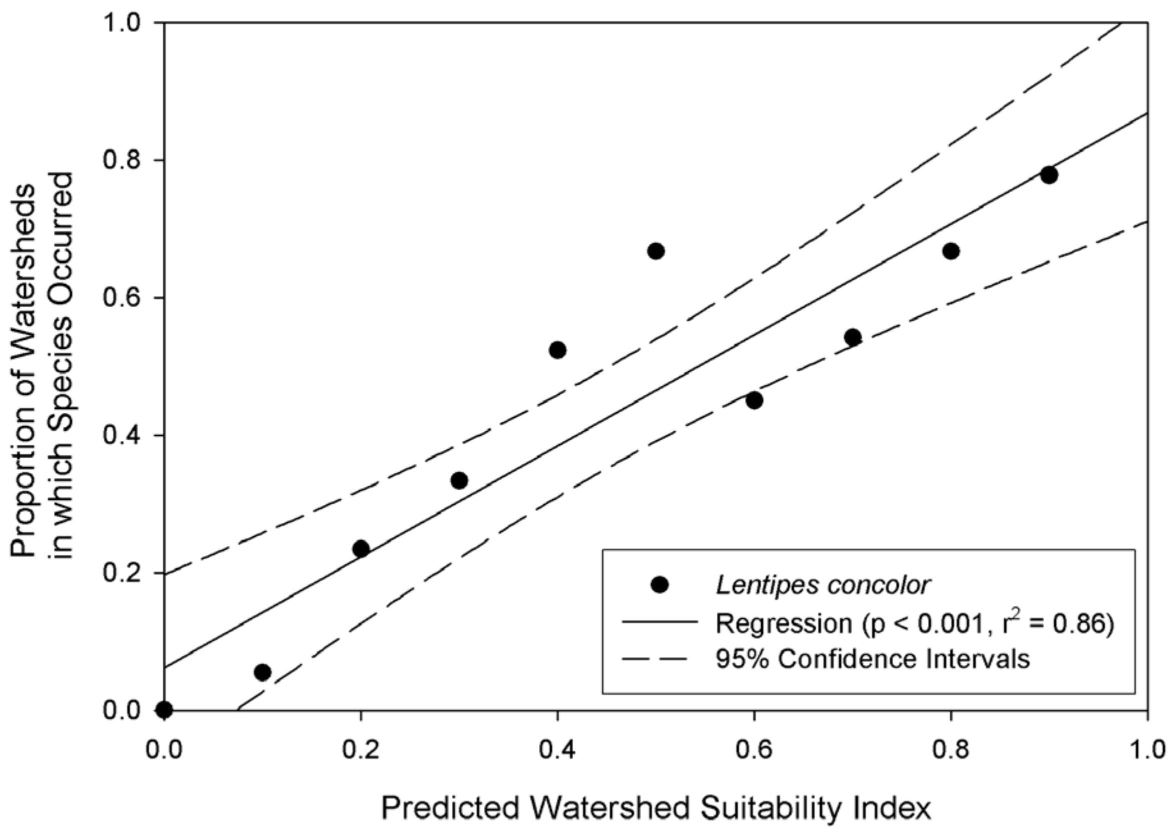

Figure 33: Proportion of the total watersheds where *Lentipes concolor* was observed within each 0.1 group of the Watershed Suitability Index equation for *Lentipes concolor*.

Sicyopterus stimpsoni:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.195 + (0.358 * \mathrm{WWR}) + (0.539 * \mathrm{WSR}) + (0.135 * \mathrm{WStR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)

WSR = Watershed Size Rating, ($p < 0.001$)

WENR = Watershed Stewardship Rating, ($p = 0.012$).

This equation had a Likelihood Ratio Test Statistic of 97.1 (P = <0.001), and correctly predicted the presence or absence of *Sicyopterus stimpsoni* in 340 of 430 watersheds (79.1% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Sicyopterus stimpsoni*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Sicyopterus stimpsoni* occurred (Figure 34).

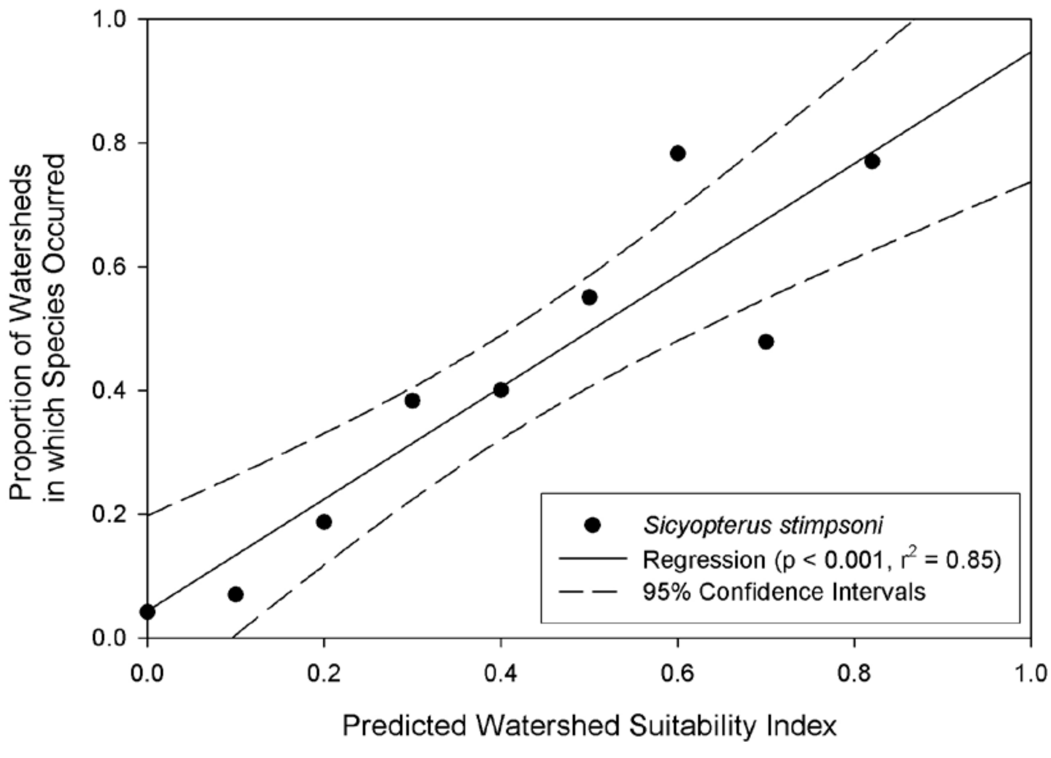

Figure 34: Proportion of the total watersheds where *Sicyopterus stimpsoni* was observed within each 0.1 group of the Watershed Suitability Index equation for *Sicyopterus stimpsoni*.

Stenogobius hawaiiensis:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.923 + (0.206 * \mathrm{WWR}) + (0.796 * \mathrm{WSR}))}}$$

where: WWR = Watershed Wetness Rating, (p = 0.003)

WSR = Watershed Size Rating, (p < 0.001).

This equation had a Likelihood Ratio Test Statistic of 73.4 (P = <0.001), and correctly predicted the presence or absence of *Stenogobius hawaiiensis* in 375 of 430 watersheds (87.2% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Stenogobius hawaiiensis*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Stenogobius hawaiiensis* occurred (Figure 35).

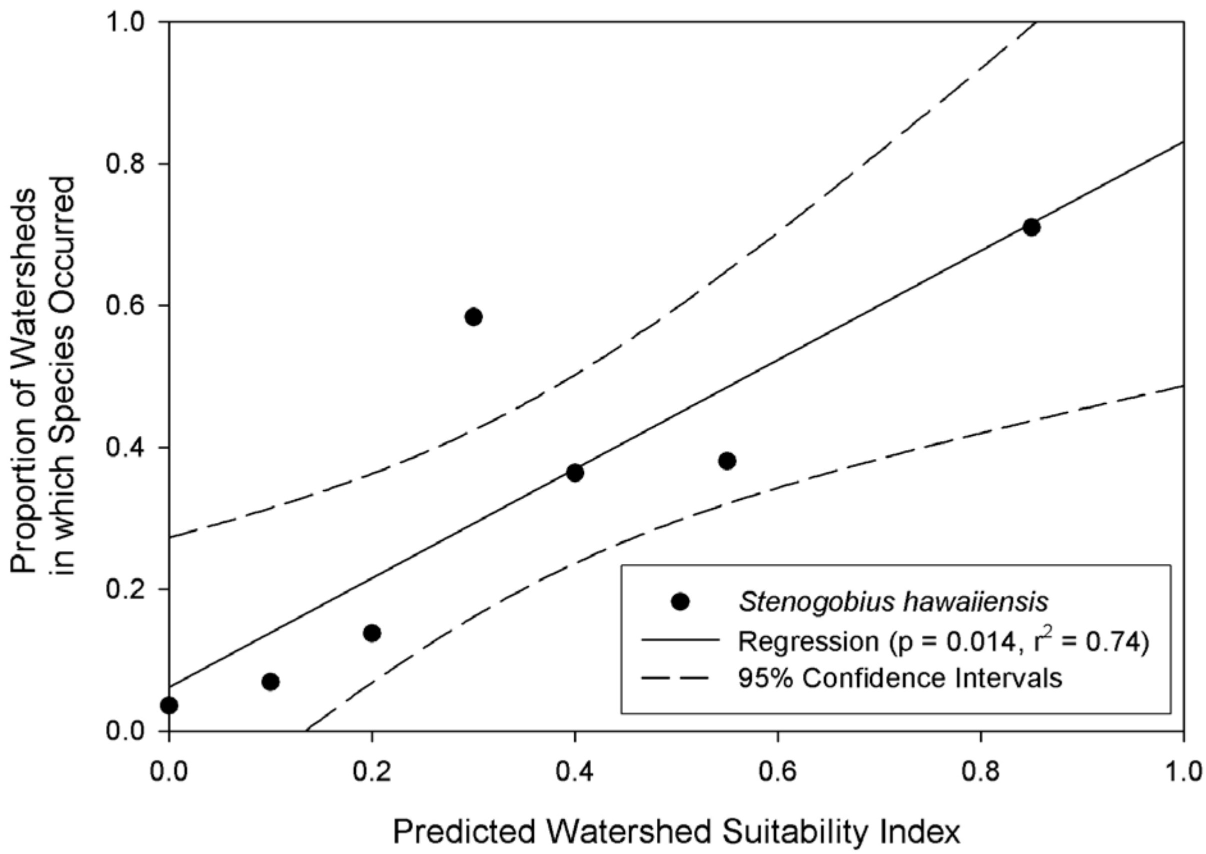

Figure 35: Proportion of the total watersheds where *Stenogobius hawaiiensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Stenogobius hawaiiensis*.

Eleotris sandwicensis:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-3.552 + (0.245 * \text{WWR}) + (0.376 * \text{WSR}) + (0.278 * \text{WENR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)

WSR = Watershed Size Rating, ($p < 0.001$)

WENR = Watershed Estuary and Nearshore Rating, ($p < 0.001$).

This equation had a Likelihood Ratio Test Statistic of 65.4 ($P = <0.001$), and correctly predicted the presence or absence of *Eleotris sandwicensis* in 343 of 430 watersheds (79.8% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Eleotris sandwicensis*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Eleotris sandwicensis* occurred (Figure 36).

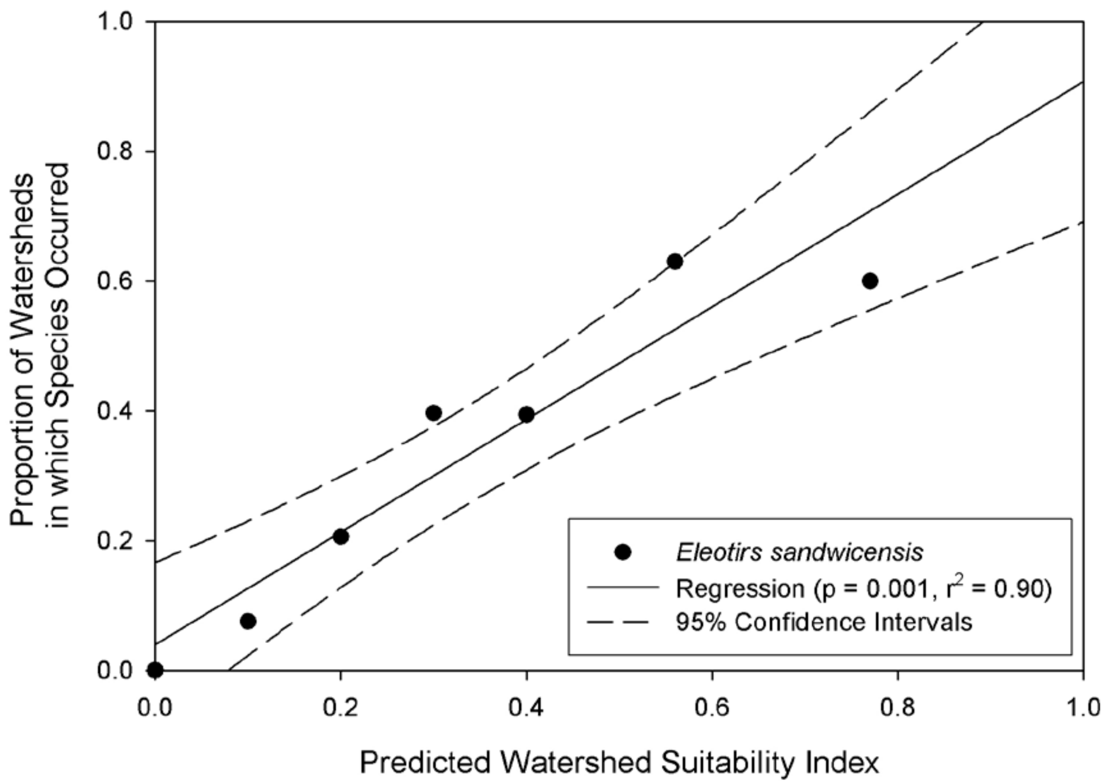

Figure 36: Proportion of the total watersheds where *Eleotris sandwicensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Eleotris sandwicensis*.

Neritina granosa:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.806 + (0.375 * \text{WWR}) + (0.435 * \text{WSR}) + (0.177 * \text{WStR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)

WSR = Watershed Size Rating, ($p < 0.001$)

WENR = Watershed Stewardship Rating, ($p = 0.003$).

This equation had a Likelihood Ratio Test Statistic of 77.5 (P = <0.001), and correctly predicted the presence or absence of *Neritina granosa* in 357 of 430 watersheds (83.0% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Neritina granosa*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Neritina granosa* occurred (Figure 37).

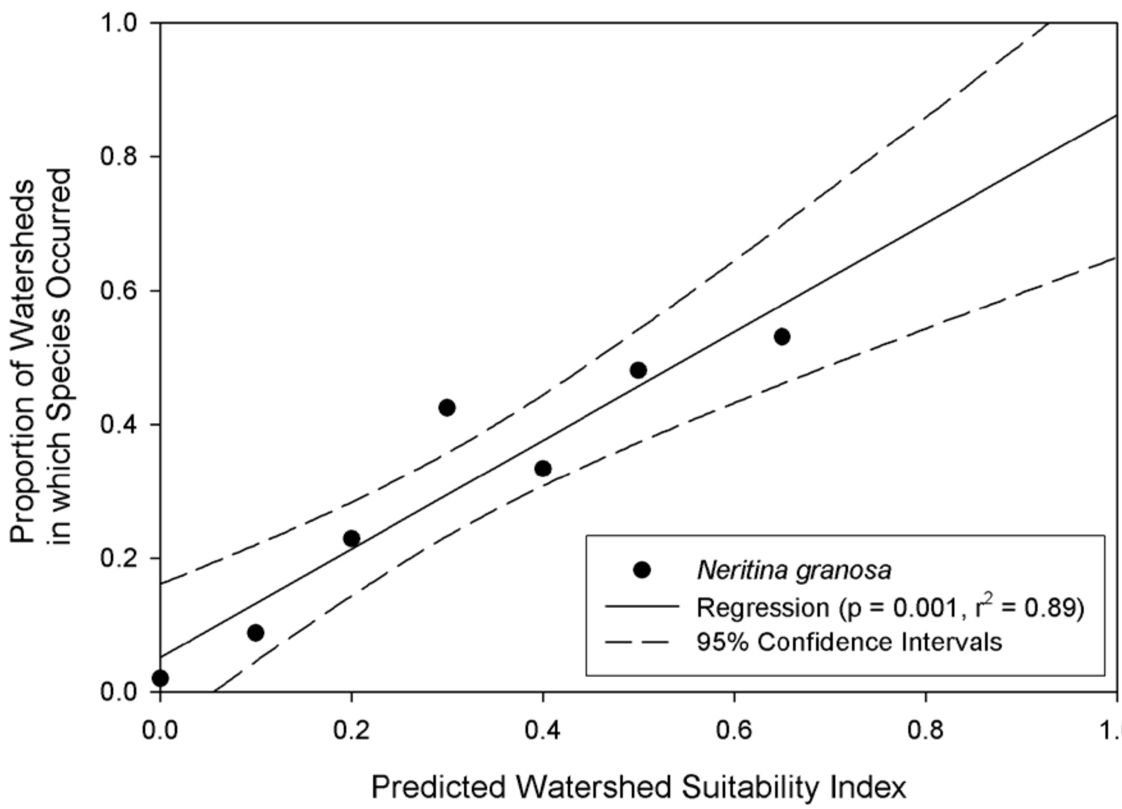

Figure 37: Proportion of the total watersheds where *Neritina granosa* was observed within each 0.1 group of the Watershed Suitability Index equation for *Neritina granosa*.

Atyoida bisulcata:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.458 + (0.508 * \text{WWR}) + (0.497 * \text{WSR}) + (0.179 * \text{WStR}) + (0.165 * \text{WENR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)

WSR = Watershed Size Rating, ($p < 0.001$)

WStR = Watershed Stewardship Rating, ($p = 0.001$)

WENR = Watershed Estuary and Nearshore Rating, ($p = 0.04$).

This equation had a Likelihood Ratio Test Statistic of 153.3 (P = <0.001), and correctly predicted the presence or absence of *Atyoida bisulcata* in 336 of 430 watersheds (78.1% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Atyoida bisulcata*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Atyoida bisulcata* occurred (Figure 38).

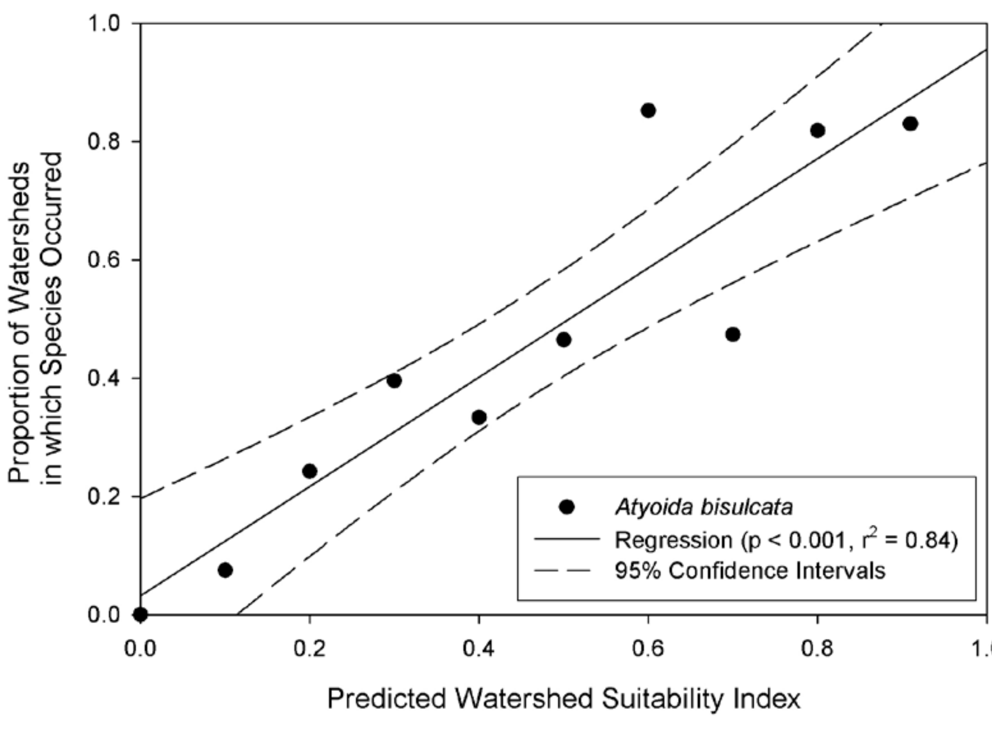

Figure 38: Proportion of the total watersheds where *Atyoida bisulcata* was observed within each 0.1 group of the Watershed Suitability Index equation for *Atyoida bisulcata*.

Macrobrachium grandimanus:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.942 + (0.286 * \mathrm{WWR}) + (0.775 * \mathrm{WSR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)

WSR = Watershed Size Rating, ($p < 0.001$).

This equation had a Likelihood Ratio Test Statistic of 82.4 (P = <0.001), and correctly predicted the presence or absence of *Macrobrachium grandimanus* in 366 of 430 watersheds (85.1% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Macrobrachium grandimanus*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Macrobrachium grandimanus* occurred (Figure 39).

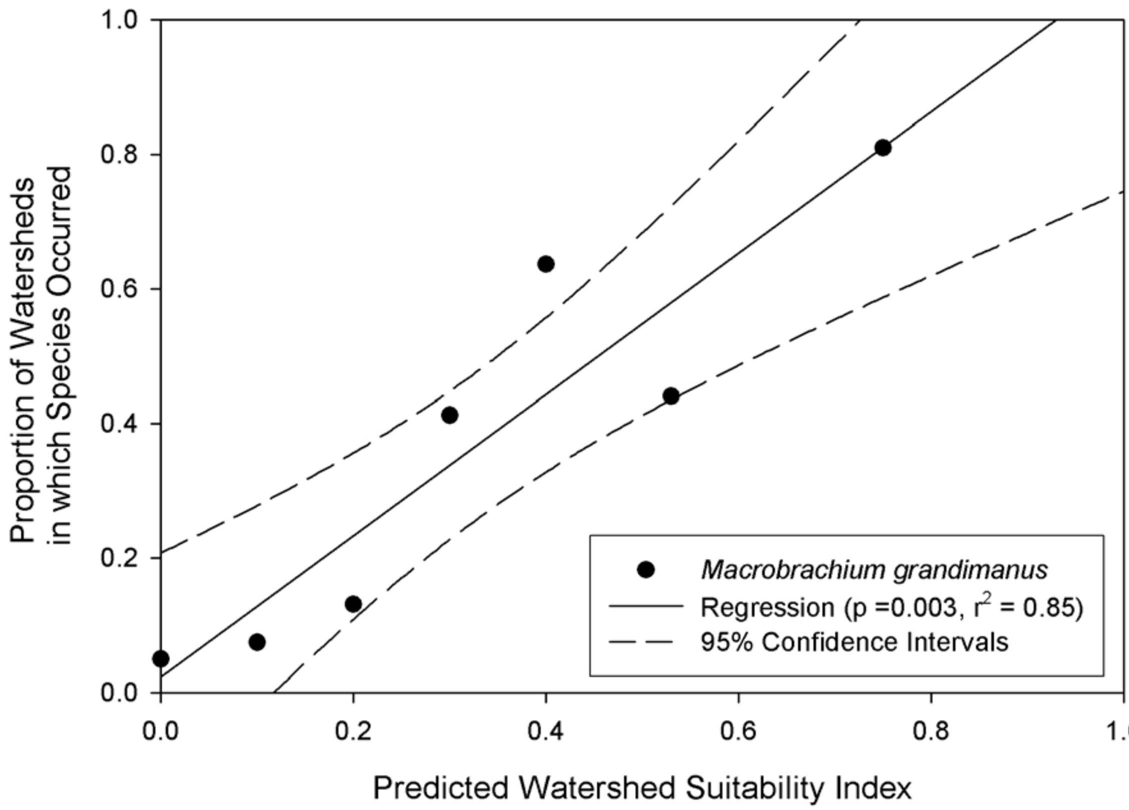

Figure 39: Proportion of the total watersheds where *Macrobrachium grandimanus* was observed within each 0.1 group of the Watershed Suitability Index equation for *Macrobrachium grandimanus*.

Appendix 2: Instream Distribution Scale:

Unlike the watershed and stream metric relationships, the instream distribution model is more of a GIS construct than a statistical construct. The data that underlies the prediction of instream distribution for the native amphidromous species comes primarily from DARs point quadrat surveys. In general, these standardized surveys have been conducted by state biologists and technicians in a wide variety of locations in many different streams across all of the lower Hawaiian Islands. The point quadrat survey is a visual survey in which both habitat and species information are recorded within a defined point in a stream. As a result, at a defined location we have a record of species occurrence. This survey location can be mapped and the co-occurring elevation, distance inland, and maximum downstream slope can be extracted from gridded GIS data. This results in a data set in which all survey points have a location, the values for the instream distribution variables, and the presence or absence of each species.

To compare the suitability for the stream animals, availability, utilization, and suitability criteria were developed following standardized procedures (Bovee and Cochnauer 1977) and as reported for Hawaiian stream animals (Parham 2008). In general, this method bases habitat utilization on the presence/absence data and does not take into account site density. Habitat availability is the frequency of each habitat category and is based on the distribution of habitats observed in the field survey. Percent availability is calculated by dividing the number of observations for a habitat category by the total number of observations and multiplying by 100. Utilization is the frequency of occurrence for an individual species in each habitat category. Percent utilization is calculated by dividing the number of sites with a species observed for a habitat category by the total number of sites with a species observed and multiplying by 100. Suitability is developed by dividing the percent utilization for each habitat category with the percent availability for each habitat category. The standardized suitability has the range adjusted so that the largest value for each species equals 1 (highly suitable) and the lowest value equals 0 (unsuitable). The smoothed standardized suitability was created by averaging the value for the bin with its two nearest neighbors. In the case of the first and last bin values, they were only averaged with the single bin next to them. The smoothed suitability was used to decrease the variation between adjacent bins as a result of same size or sample distribution.

The decision on the bin sizes for the various continuous variables was set subjectively to balance several factors. First, the number of samples in each bin attempted to have at least 200 observations from the total number of samples. Next, the bin sizes were adjusted to make the number of samples in each bin as consistent as possible, and finally, the bins were distributed to cover a range of biologically meaningful values. For example, the native amphidromous animals migrate upstream from the ocean. As the elevation increases different species are less likely to be observed, therefore, the elevation bins are more closely spaced at lower elevations and more widely spaced at higher elevations to see changes that occur as the animals move upstream.

The selection of animals included in this analysis was based on the overall number of sites in which the animals were observed. In most cases, at least 50 independent site observations were needed to include the animal in development of specific suitability criteria, although in some cases smaller sample sizes were accepted if the species had consistently been observed in other suitability criteria variables. In a perfect database, all observations of the animals would have all of the information included, but in many cases, the information for certain variables were not recorded so sample size varies among criteria. The database and spreadsheets are designed to allow changes in bin distribution or species to allow user adjustment to account for specific project needs.

GIS Suitability Modeling

The use of table based suitability criteria was in part based on the desire to allow rapid integration of the results with the GIS map-based analyses. The spreadsheet results were multiplied by 100 and then converted to integer values to fit the GIS reclassification requirements. The bins were split into a “from value” and “to value” with the integer suitability for each species in the subsequent columns. For example using elevation, the “from value” may be 0 and the “to value” was 2, the next “from value” would be 3 to 5, etc. No overlap of subsequent “from” and “to” values are allowed, although the “from” and “to” value on an individual line can be the same value.

After converting the suitability table to the reclassification format, the spreadsheet was converted to a database table (dbf). Next, the dbf table was imported into ArcGIS. In ArcGIS, the distributional layers were added to the map. Each layer was developed in previous work from the

USGS 10 meter digital elevation model. The distribution layers of elevation, distance inland, and maximum downstream slope were used to predict instream distribution of the native amphidromous animals. Prediction of the instream distribution of introduced animals is difficult as most of their locations are based on proximity to the place of introduction in the stream and not migration.

The instream distributional variables were combined by using map algebra where the results of each of the suitability criteria layers were multiplied together to describe a range of conditions from most to least suitable in a stream. Within the stream sections that a species is expected to occur, the habitat suitability criteria describe the suitable habitat for the species. To determine the appropriate combination method within the ArcGIS map algebra, two of the most commonly used methods were tried. These combination methods were an additive model and a multiplicative model.

- Instream Distribution Suitability = (Elevation Suitability + Distance Inland Suitability + Downstream Barrier Height Suitability)
  where: if Elevation Suitability or Distance Inland Suitability or Downstream Barrier Height Suitability = 0, then Reach Suitability = 0
- Instream Distribution Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

To determine which of these combination methods were more appropriate for an individual species, the variables for elevation, distance inland, and downstream barrier height were combined using two different relationships. Next, each relationship was range standardized with a minimum value of 0 and a maximum value of 1. Then, the results of each relationship for all sites with all data for each variable in the database were calculated. The sites were grouped with the predicted results into bins from 0 to 1 by tenths, and the proportion of samples with the species of concern was determined for each group. In cases where too few samples occurred in a bin (usually fewer than 100 of the 8300 samples in a single bin), the results were averaged with the nearest bin containing the fewest samples. The results of the comparison of predicted suitability with the proportion of samples containing a species were plotted on a graph and analyzed using linear regression.

To select the more appropriate relationship, two criteria were used. First, the distribution of predicted results to observed proportions was visually compared. If predicted values between 0 and 1 resulted in a range of proportions between 0 and 1, the relationship was considered acceptable. If both relationships were acceptable to the first criteria, then the relationship with the higher r^2 value for the linear regression was chosen.

Figure 40 to Figure 45 graphically show the suitability for the native amphidromous stream animals. While Table 2 to Table 25 show the bins, frequency, utilization, suitability, and smooth suitability for the species. Finally, Figure 46 to Figure 53 show the selected combination method and its associated linear regression with statistics for each species.

Elevation Suitability Indices

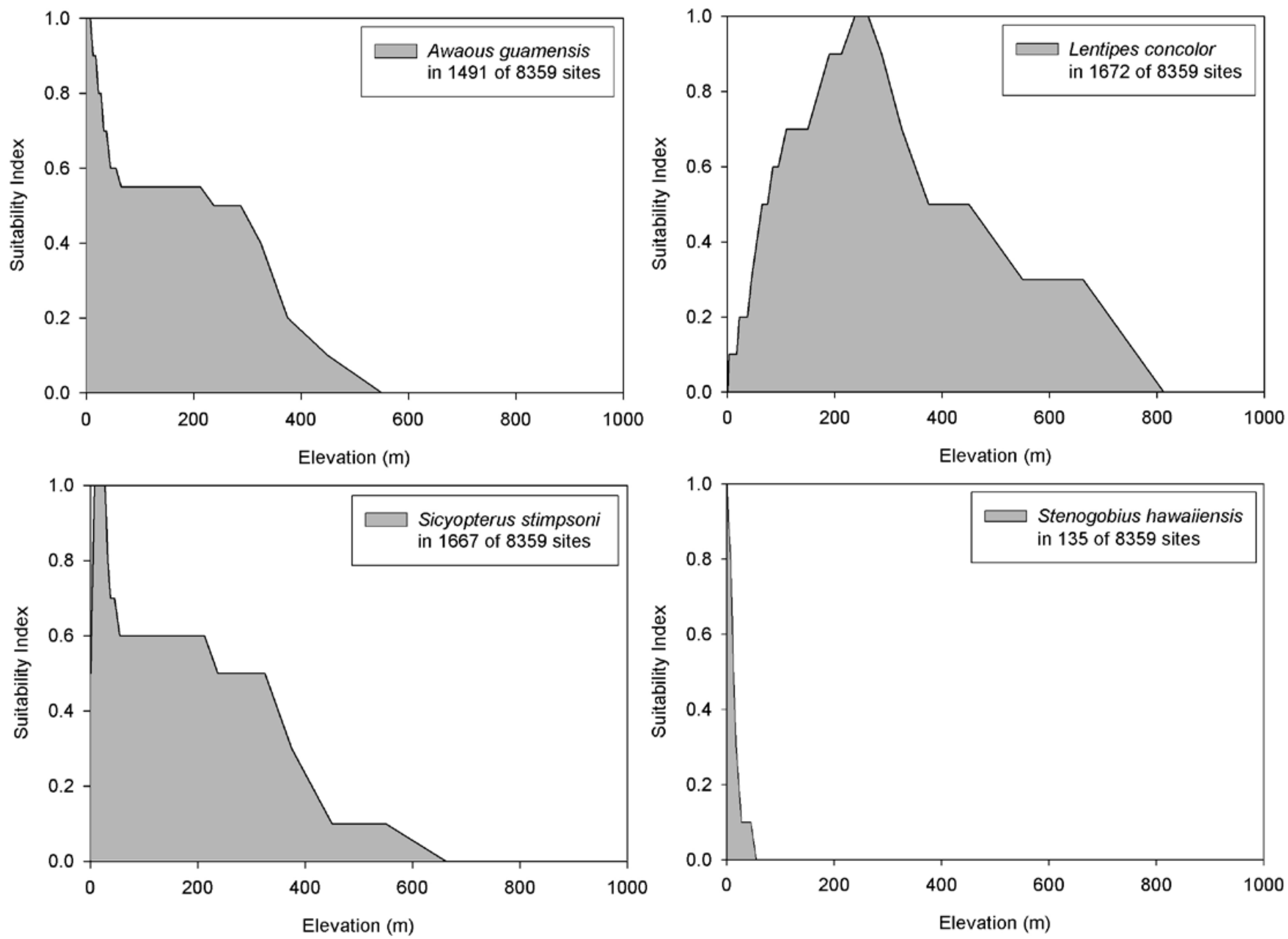

Figure 40: Suitability Indices for Elevation for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

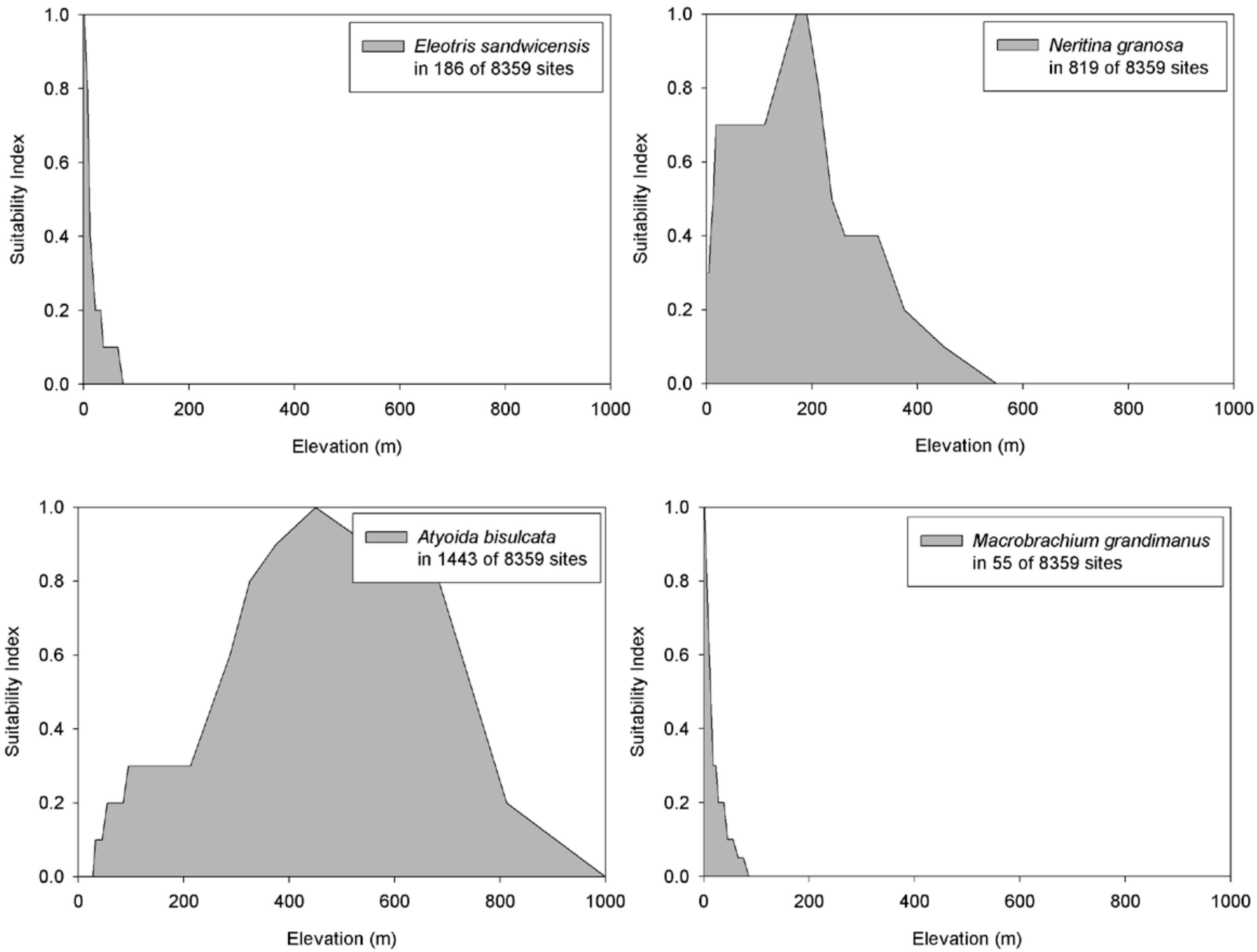

Figure 41: Suitability Indices for Elevation for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

Distance Inland Suitability Indices

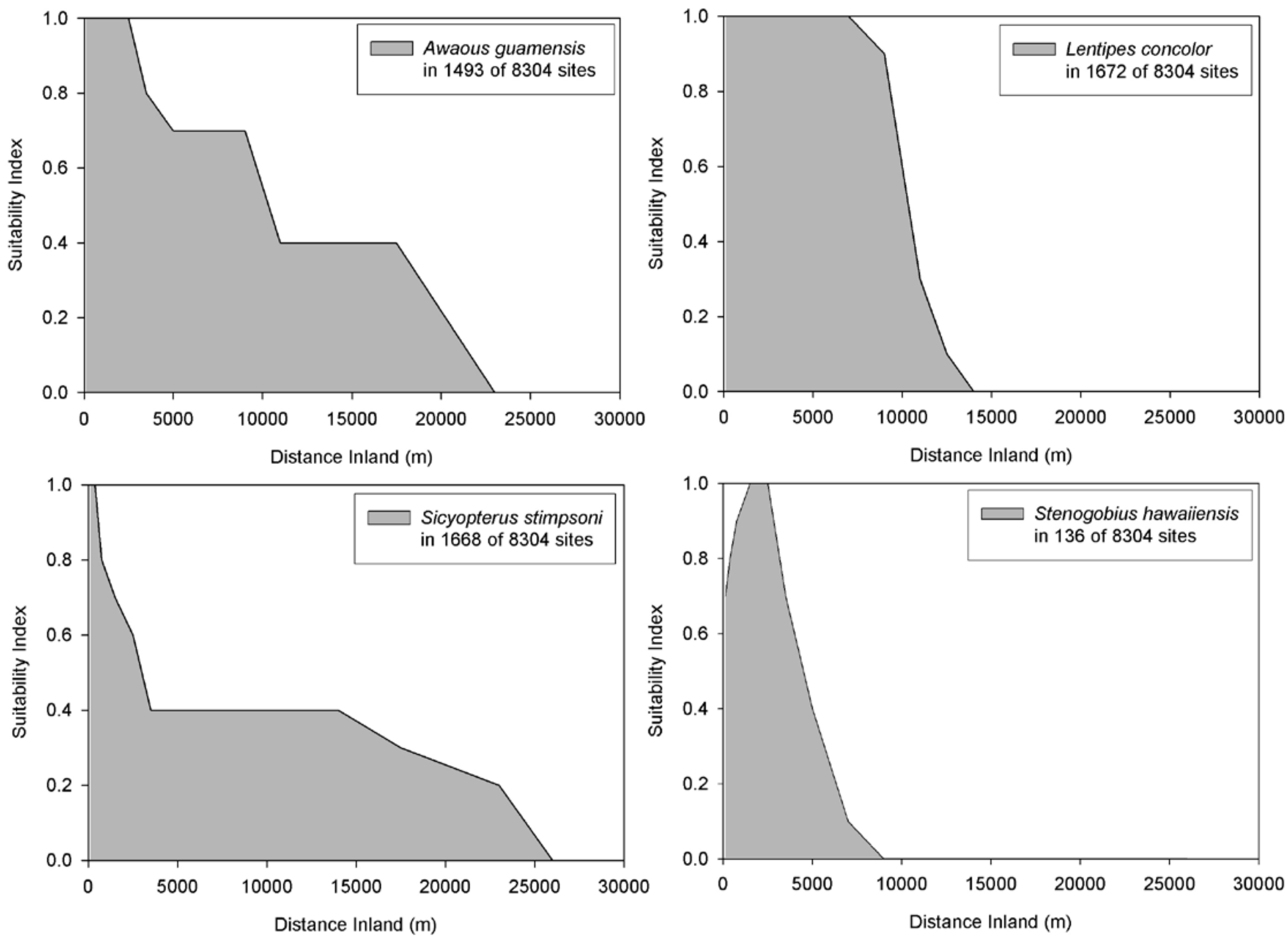

Figure 42: Suitability Indices for Distance Inland for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

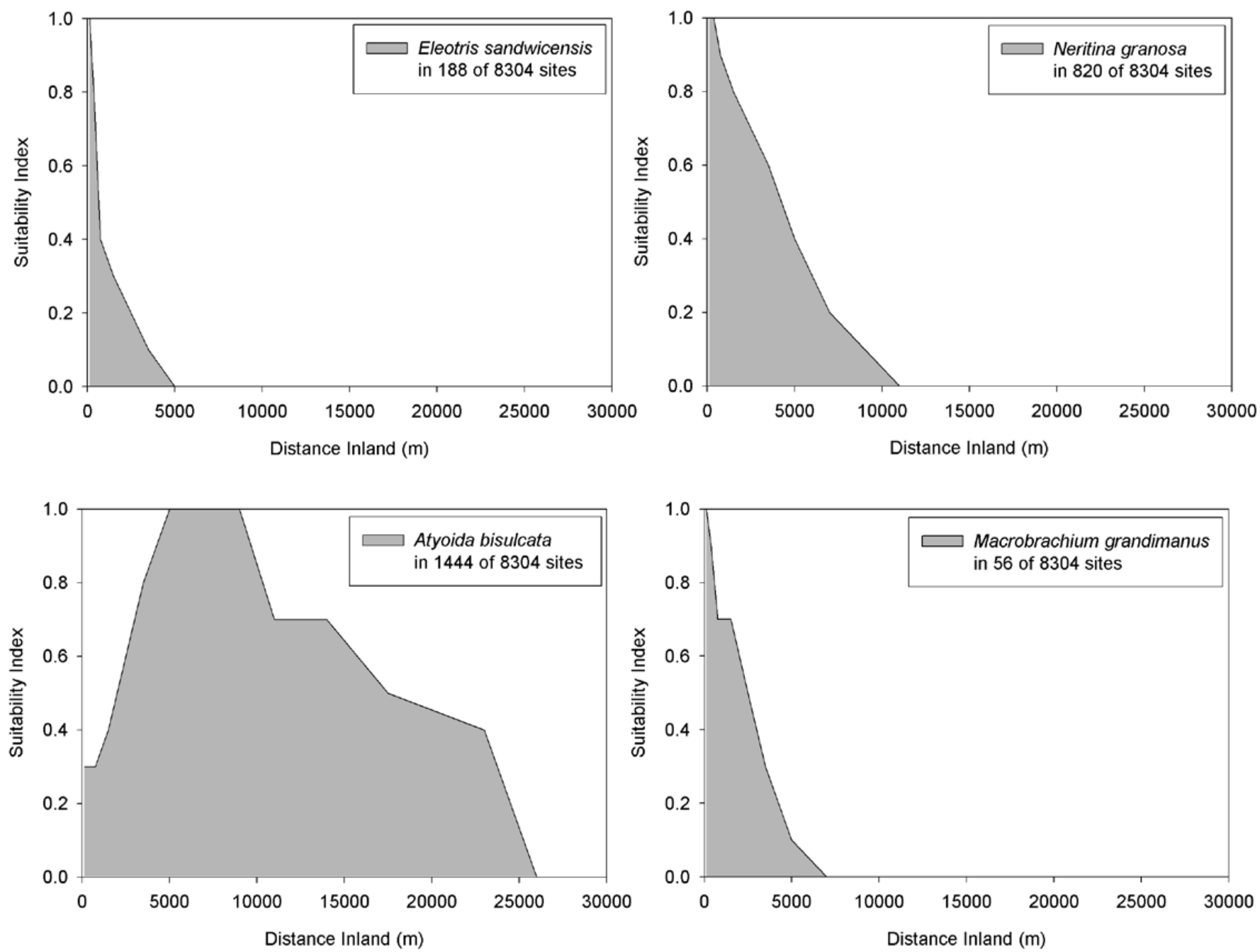

Figure 43: Suitability Indices for Distance Inland for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Barrier Height Suitability Indices

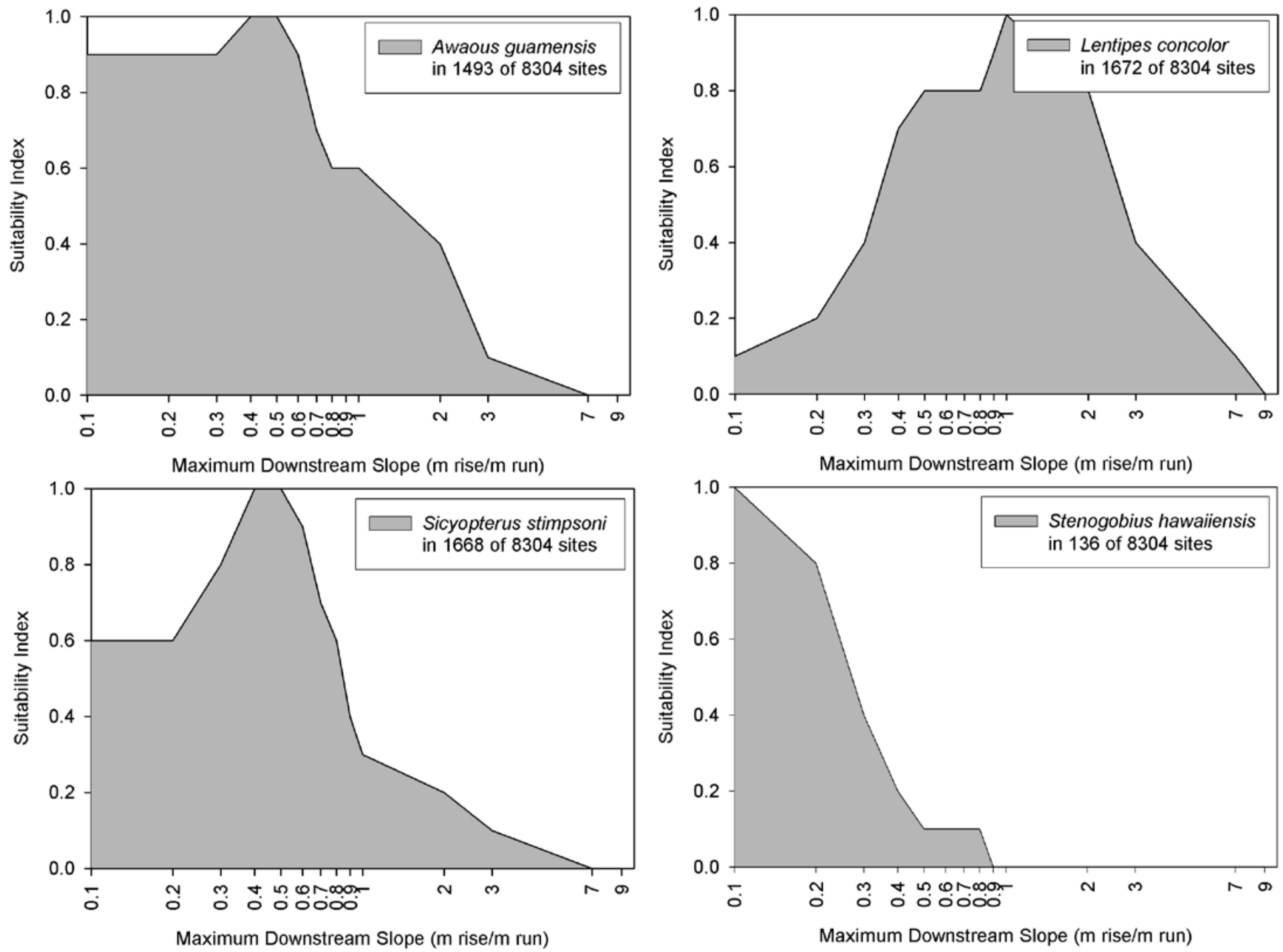

Figure 44: Suitability Indices for Barriers (maximum downstream slope over 10m distance) for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

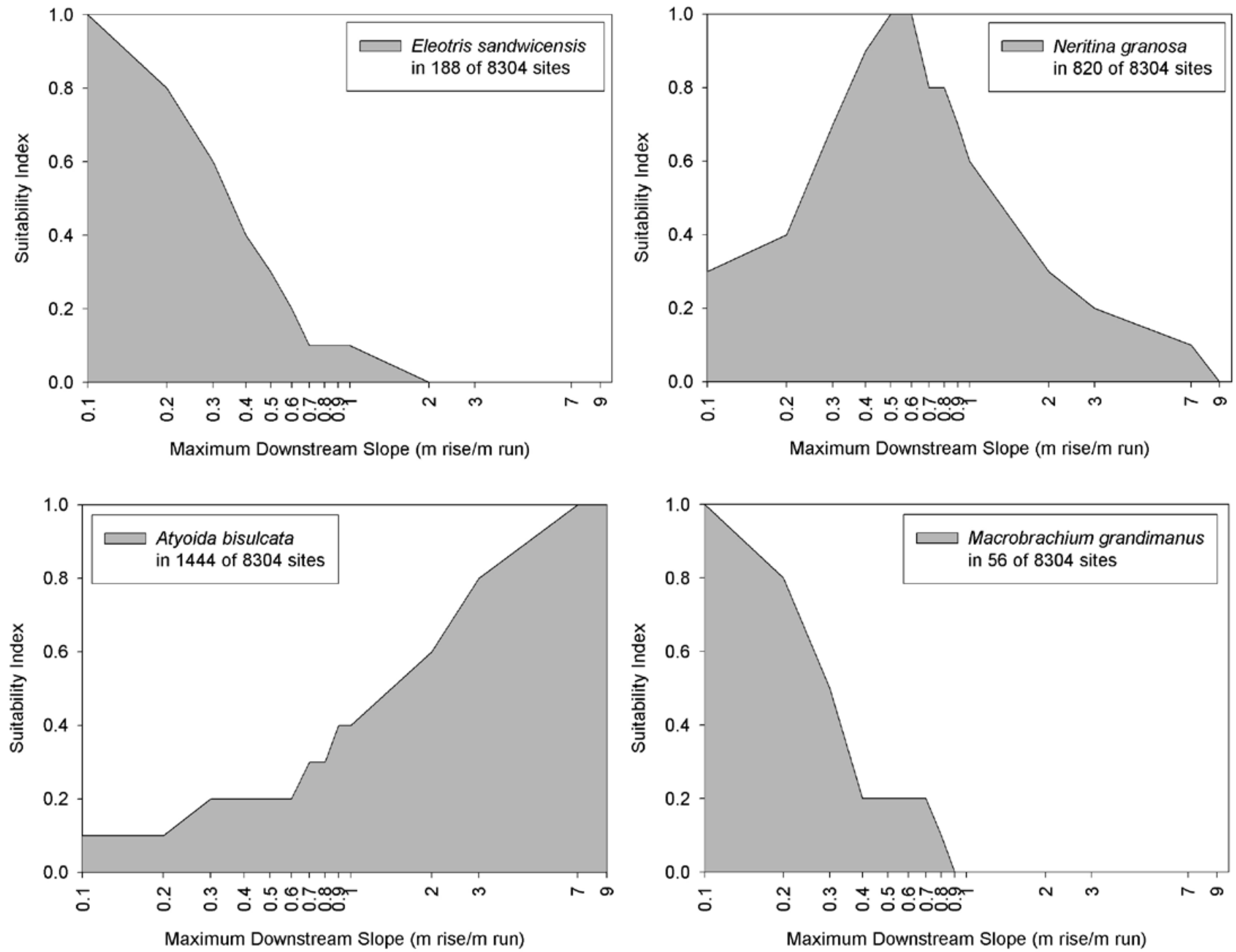

Figure 45: Suitability Indices for Barriers (maximum downstream slope over 10m distance) for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Table 2: Frequency of occurrence for site elevation (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database.

Elevation Bin	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
2	111	1	29	12	1	27	1	5	9	2	33	3	4	6	12	5	8
5	331	5	109	56	2	71	11	11	47	35	70	1	2	87	38	4	7
10	470	12	136	46	12	63	15	14	105	31	100	13	3	162	36	6	33
15	333	5	93	18	9	20	12	7	61	20	89	12	9	111	20	8	20
20	274	9	73	5	6	10	14	3	51	41	77	9	3	78	8	6	23
25	315	4	76	14	3	29	18	2	60	53	84	11	2	100	6	6	27
30	243	7	55	9	3	6	34	3	60	34	74	7	1	83	6	2	17
35	306	10	78	5	2	9	22	3	81	40	84	15	3	79	1	4	37
40	186	10	34	8	2	2	18	0	53	26	57	7	1	40	2	3	22
50	355	23	71	1	6	2	41	3	66	28	130	25	4	70	1	6	45
60	414	44	71	6	4	4	82	0	85	50	144	11	15	91	3	9	31
70	284	38	53	2	2	1	58	1	76	19	90	4	5	55	1	2	23
80	393	46	51	1	1	5	94	0	81	31	151	3	7	59	0	4	8
90	245	30	24	0	1	0	47	1	51	15	111	5	4	34	0	8	6
100	174	30	26	0	0	2	47	0	36	16	62	5	2	40	0	3	5
120	319	59	68	1	2	1	106	2	74	43	86	11	7	57	1	17	8
140	324	53	46	0	2	0	101	0	81	51	87	9	5	53	0	14	4
160	296	42	70	0	2	0	88	0	69	46	87	16	5	68	0	3	13
180	311	41	55	1	2	0	102	0	56	60	86	13	5	89	0	4	4
200	220	41	52	0	3	0	83	0	27	45	60	10	2	48	0	4	8
225	288	43	49	0	1	0	110	0	42	46	88	9	2	48	0	9	4
250	287	50	44	1	3	0	102	0	28	19	100	8	3	43	0	7	3
275	215	55	24	0	1	1	114	0	21	10	46	1	1	29	0	4	4
300	189	64	41	0	0	0	71	0	2	22	47	0	1	41	0	0	1
350	298	122	37	0	2	0	69	0	15	17	81	4	1	52	0	6	2
400	278	147	17	0	2	0	71	0	2	8	99	1	6	16	0	2	1
500	406	192	5	0	2	0	77	0	2	10	173	0	1	21	0	0	2
600	320	209	0	0	6	0	50	0	1	1	76	0	26	5	0	0	41
700	126	45	4	0	1	0	8	0	0	0	69	2	5	2	0	0	7
1000	44	6	0	0	0	0	6	0	0	0	31	0	0	0	0	0	0
1000+	4	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Total	8359	1443	1491	186	83	253	1672	55	1342	819	2576	215	135	1667	135	146	414

Table 3: Percent Utilization for site elevation (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database.

Elevation Bin	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
2	1.3	0.1	1.9	6.5	1.2	10.7	0.1	9.1	0.7	0.2	1.3	1.4	3.0	0.4	8.9	3.4	1.9
5	4.0	0.3	7.3	30.1	2.4	28.1	0.7	20.0	3.5	4.3	2.7	0.5	1.5	5.2	28.1	2.7	1.7
10	5.6	0.8	9.1	24.7	14.5	24.9	0.9	25.5	7.8	3.8	3.9	6.0	2.2	9.7	26.7	4.1	8.0
15	4.0	0.3	6.2	9.7	10.8	7.9	0.7	12.7	4.5	2.4	3.5	5.6	6.7	6.7	14.8	5.5	4.8
20	3.3	0.6	4.9	2.7	7.2	4.0	0.8	5.5	3.8	5.0	3.0	4.2	2.2	4.7	5.9	4.1	5.6
25	3.8	0.3	5.1	7.5	3.6	11.5	1.1	3.6	4.5	6.5	3.3	5.1	1.5	6.0	4.4	4.1	6.5
30	2.9	0.5	3.7	4.8	3.6	2.4	2.0	5.5	4.5	4.2	2.9	3.3	0.7	5.0	4.4	1.4	4.1
35	3.7	0.7	5.2	2.7	2.4	3.6	1.3	5.5	6.0	4.9	3.3	7.0	2.2	4.7	0.7	2.7	8.9
40	2.2	0.7	2.3	4.3	2.4	0.8	1.1	0.0	3.9	3.2	2.2	3.3	0.7	2.4	1.5	2.1	5.3
50	4.2	1.6	4.8	0.5	7.2	0.8	2.5	5.5	4.9	3.4	5.0	11.6	3.0	4.2	0.7	4.1	10.9
60	5.0	3.0	4.8	3.2	4.8	1.6	4.9	0.0	6.3	6.1	5.6	5.1	11.1	5.5	2.2	6.2	7.5
70	3.4	2.6	3.6	1.1	2.4	0.4	3.5	1.8	5.7	2.3	3.5	1.9	3.7	3.3	0.7	1.4	5.6
80	4.7	3.2	3.4	0.5	1.2	2.0	5.6	0.0	6.0	3.8	5.9	1.4	5.2	3.5	0.0	2.7	1.9
90	2.9	2.1	1.6	0.0	1.2	0.0	2.8	1.8	3.8	1.8	4.3	2.3	3.0	2.0	0.0	5.5	1.4
100	2.1	2.1	1.7	0.0	0.0	0.8	2.8	0.0	2.7	2.0	2.4	2.3	1.5	2.4	0.0	2.1	1.2
120	3.8	4.1	4.6	0.5	2.4	0.4	6.3	3.6	5.5	5.3	3.3	5.1	5.2	3.4	0.7	11.6	1.9
140	3.9	3.7	3.1	0.0	2.4	0.0	6.0	0.0	6.0	6.2	3.4	4.2	3.7	3.2	0.0	9.6	1.0
160	3.5	2.9	4.7	0.0	2.4	0.0	5.3	0.0	5.1	5.6	3.4	7.4	3.7	4.1	0.0	2.1	3.1
180	3.7	2.8	3.7	0.5	2.4	0.0	6.1	0.0	4.2	7.3	3.3	6.0	3.7	5.3	0.0	2.7	1.0
200	2.6	2.8	3.5	0.0	3.6	0.0	5.0	0.0	2.0	5.5	2.3	4.7	1.5	2.9	0.0	2.7	1.9
225	3.4	3.0	3.3	0.0	1.2	0.0	6.6	0.0	3.1	5.6	3.4	4.2	1.5	2.9	0.0	6.2	1.0
250	3.4	3.5	3.0	0.5	3.6	0.0	6.1	0.0	2.1	2.3	3.9	3.7	2.2	2.6	0.0	4.8	0.7
275	2.6	3.8	1.6	0.0	1.2	0.4	6.8	0.0	1.6	1.2	1.8	0.5	0.7	1.7	0.0	2.7	1.0
300	2.3	4.4	2.7	0.0	0.0	0.0	4.2	0.0	0.1	2.7	1.8	0.0	0.7	2.5	0.0	0.0	0.2
350	3.6	8.5	2.5	0.0	2.4	0.0	4.1	0.0	1.1	2.1	3.1	1.9	0.7	3.1	0.0	4.1	0.5
400	3.3	10.2	1.1	0.0	2.4	0.0	4.2	0.0	0.1	1.0	3.8	0.5	4.4	1.0	0.0	1.4	0.2
500	4.9	13.3	0.3	0.0	2.4	0.0	4.6	0.0	0.1	1.2	6.7	0.0	0.7	1.3	0.0	0.0	0.5
600	3.8	14.5	0.0	0.0	7.2	0.0	3.0	0.0	0.1	0.1	3.0	0.0	19.3	0.3	0.0	0.0	9.9
700	1.5	3.1	0.3	0.0	1.2	0.0	0.5	0.0	0.0	0.0	2.7	0.9	3.7	0.1	0.0	0.0	1.7
1000	0.5	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
1000+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0

Table 4: Standardized suitability for site elevation (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database. Standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Elevation Bin	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
2	1	0.01	0.79	0.64	0.33	1.00	0.02	1.00	0.28	0.09	0.30	0.38	0.44	0.16	0.94	0.85	0.56
5	1	0.02	1.00	1.00	0.22	0.88	0.06	0.74	0.50	0.52	0.21	0.04	0.07	0.76	1.00	0.23	0.17
10	1	0.04	0.88	0.58	0.94	0.55	0.06	0.66	0.78	0.32	0.21	0.39	0.08	1.00	0.67	0.24	0.55
15	1	0.02	0.85	0.32	1.00	0.25	0.07	0.47	0.64	0.29	0.27	0.51	0.33	0.97	0.52	0.45	0.47
20	1	0.05	0.81	0.11	0.81	0.15	0.10	0.24	0.65	0.73	0.28	0.47	0.13	0.83	0.25	0.41	0.66
25	1	0.02	0.73	0.26	0.35	0.38	0.11	0.14	0.67	0.82	0.27	0.50	0.08	0.92	0.17	0.36	0.67
30	1	0.04	0.69	0.22	0.46	0.10	0.26	0.27	0.87	0.68	0.30	0.41	0.05	0.99	0.22	0.15	0.55
35	1	0.05	0.77	0.10	0.24	0.12	0.14	0.22	0.93	0.64	0.27	0.70	0.12	0.75	0.03	0.25	0.94
40	1	0.08	0.56	0.25	0.40	0.04	0.18	0.00	1.00	0.68	0.31	0.53	0.07	0.62	0.09	0.30	0.92
50	1	0.10	0.61	0.02	0.63	0.02	0.22	0.19	0.65	0.39	0.37	1.00	0.14	0.57	0.02	0.32	0.99
60	1	0.16	0.52	0.09	0.36	0.04	0.37	0.00	0.72	0.59	0.35	0.38	0.45	0.64	0.06	0.41	0.58
70	1	0.20	0.57	0.04	0.26	0.01	0.39	0.08	0.94	0.33	0.32	0.20	0.22	0.56	0.03	0.13	0.63
80	1	0.18	0.39	0.02	0.09	0.05	0.45	0.00	0.72	0.39	0.38	0.11	0.22	0.44	0.00	0.19	0.16
90	1	0.19	0.30	0.00	0.15	0.00	0.36	0.09	0.73	0.30	0.45	0.29	0.20	0.40	0.00	0.61	0.19
100	1	0.26	0.45	0.00	0.00	0.05	0.51	0.00	0.73	0.45	0.36	0.41	0.14	0.67	0.00	0.32	0.22
120	1	0.28	0.65	0.02	0.23	0.01	0.63	0.14	0.81	0.66	0.27	0.49	0.27	0.52	0.03	1.00	0.20
140	1	0.25	0.43	0.00	0.23	0.00	0.59	0.00	0.88	0.77	0.27	0.39	0.19	0.47	0.00	0.81	0.10
160	1	0.22	0.72	0.00	0.25	0.00	0.56	0.00	0.82	0.76	0.29	0.77	0.21	0.67	0.00	0.19	0.34
180	1	0.20	0.54	0.02	0.24	0.00	0.62	0.00	0.63	0.94	0.28	0.59	0.20	0.83	0.00	0.24	0.10
200	1	0.29	0.72	0.00	0.50	0.00	0.71	0.00	0.43	1.00	0.27	0.65	0.11	0.63	0.00	0.34	0.28
225	1	0.23	0.52	0.00	0.13	0.00	0.72	0.00	0.51	0.78	0.31	0.44	0.09	0.48	0.00	0.59	0.11
250	1	0.27	0.47	0.02	0.39	0.00	0.67	0.00	0.34	0.32	0.35	0.40	0.13	0.43	0.00	0.46	0.08
275	1	0.39	0.34	0.00	0.17	0.02	1.00	0.00	0.34	0.23	0.21	0.07	0.06	0.39	0.00	0.35	0.15
300	1	0.52	0.66	0.00	0.00	0.00	0.71	0.00	0.04	0.57	0.25	0.00	0.07	0.63	0.00	0.00	0.04
350	1	0.63	0.38	0.00	0.25	0.00	0.44	0.00	0.18	0.28	0.27	0.19	0.04	0.51	0.00	0.38	0.05
400	1	0.81	0.19	0.00	0.27	0.00	0.48	0.00	0.03	0.14	0.36	0.05	0.27	0.17	0.00	0.13	0.03
500	1	0.72	0.04	0.00	0.18	0.00	0.36	0.00	0.02	0.12	0.43	0.00	0.03	0.15	0.00	0.00	0.04
600	1	1.00	0.00	0.00	0.69	0.00	0.29	0.00	0.01	0.02	0.24	0.00	1.00	0.05	0.00	0.00	1.00
700	1	0.55	0.10	0.00	0.29	0.00	0.12	0.00	0.00	0.00	0.55	0.23	0.49	0.05	0.00	0.00	0.43
1000	1	0.21	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00
1000+	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5: Smoothed standardized suitability for site elevation (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database. Smoothed standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Elevation Bin	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
2	1	0.02	0.90	0.82	0.28	0.94	0.04	0.87	0.39	0.30	0.25	0.21	0.26	0.46	0.97	0.54	0.36
5	1	0.03	0.89	0.74	0.50	0.81	0.05	0.80	0.52	0.31	0.24	0.27	0.20	0.64	0.87	0.44	0.43
10	1	0.03	0.91	0.63	0.72	0.56	0.06	0.62	0.64	0.38	0.23	0.32	0.16	0.91	0.73	0.31	0.39
15	1	0.04	0.85	0.34	0.92	0.32	0.07	0.46	0.69	0.45	0.25	0.46	0.18	0.93	0.48	0.37	0.56
20	1	0.03	0.80	0.23	0.72	0.26	0.09	0.28	0.65	0.62	0.27	0.49	0.18	0.90	0.31	0.41	0.60
25	1	0.04	0.74	0.20	0.54	0.21	0.16	0.22	0.73	0.75	0.28	0.46	0.09	0.91	0.21	0.31	0.62
30	1	0.04	0.73	0.19	0.35	0.20	0.17	0.21	0.82	0.72	0.28	0.53	0.08	0.89	0.14	0.25	0.72
35	1	0.06	0.67	0.19	0.37	0.09	0.19	0.16	0.93	0.67	0.30	0.55	0.08	0.79	0.11	0.23	0.80
40	1	0.08	0.65	0.12	0.42	0.06	0.18	0.14	0.86	0.57	0.32	0.74	0.11	0.65	0.05	0.29	0.95
50	1	0.11	0.56	0.12	0.46	0.04	0.26	0.06	0.79	0.55	0.34	0.64	0.22	0.61	0.06	0.34	0.83
60	1	0.16	0.56	0.05	0.41	0.03	0.33	0.09	0.77	0.43	0.34	0.53	0.27	0.59	0.04	0.29	0.74
70	1	0.18	0.49	0.05	0.24	0.04	0.40	0.03	0.79	0.43	0.35	0.23	0.29	0.55	0.03	0.24	0.46
80	1	0.19	0.42	0.02	0.17	0.02	0.40	0.06	0.80	0.34	0.38	0.20	0.21	0.47	0.01	0.31	0.33
90	1	0.21	0.38	0.01	0.08	0.03	0.44	0.03	0.73	0.38	0.40	0.27	0.19	0.50	0.00	0.38	0.19
100	1	0.24	0.47	0.01	0.13	0.02	0.50	0.08	0.76	0.47	0.36	0.40	0.20	0.53	0.01	0.65	0.20
120	1	0.27	0.51	0.01	0.15	0.02	0.57	0.05	0.81	0.63	0.30	0.43	0.20	0.55	0.01	0.71	0.17
140	1	0.25	0.60	0.01	0.24	0.00	0.59	0.05	0.84	0.73	0.28	0.55	0.22	0.55	0.01	0.67	0.21
160	1	0.22	0.56	0.01	0.24	0.00	0.59	0.00	0.78	0.82	0.28	0.59	0.20	0.66	0.00	0.41	0.18
180	1	0.23	0.66	0.01	0.33	0.00	0.63	0.00	0.63	0.90	0.28	0.67	0.17	0.71	0.00	0.26	0.24
200	1	0.24	0.59	0.01	0.29	0.00	0.68	0.00	0.52	0.91	0.28	0.56	0.13	0.65	0.00	0.39	0.16
225	1	0.26	0.57	0.01	0.34	0.00	0.70	0.00	0.43	0.70	0.31	0.50	0.11	0.52	0.00	0.46	0.16
250	1	0.30	0.44	0.01	0.23	0.01	0.80	0.00	0.40	0.44	0.29	0.30	0.09	0.44	0.00	0.46	0.11
275	1	0.39	0.49	0.01	0.19	0.01	0.79	0.00	0.24	0.37	0.27	0.15	0.08	0.49	0.00	0.27	0.09
300	1	0.51	0.46	0.00	0.14	0.01	0.72	0.00	0.19	0.36	0.24	0.09	0.05	0.51	0.00	0.24	0.08
350	1	0.65	0.41	0.00	0.17	0.00	0.54	0.00	0.08	0.33	0.29	0.08	0.12	0.43	0.00	0.17	0.04
400	1	0.72	0.20	0.00	0.23	0.00	0.43	0.00	0.07	0.18	0.35	0.08	0.11	0.27	0.00	0.17	0.04
500	1	0.84	0.07	0.00	0.38	0.00	0.38	0.00	0.02	0.09	0.34	0.02	0.43	0.12	0.00	0.04	0.36
600	1	0.76	0.04	0.00	0.39	0.00	0.26	0.00	0.01	0.05	0.40	0.08	0.51	0.08	0.00	0.00	0.49
700	1	0.59	0.03	0.00	0.33	0.00	0.22	0.00	0.00	0.01	0.50	0.08	0.50	0.03	0.00	0.00	0.48
1000	1	0.25	0.03	0.00	0.10	0.00	0.13	0.00	0.00	0.00	0.75	0.08	0.16	0.02	0.00	0.00	0.14
1000+	1	0.10	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00

Table 6: Frequency of occurrence for distance inland (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database.

Distance Inland (m)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	*Neritina vespertina*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
250	763	53	182	86	9	115	134	18	193	100	10	110	16	7	270	15	2	8
500	653	55	105	24	9	40	154	1	150	115	0	167	9	7	184	9	1	13
1,000	1050	101	191	24	13	34	250	10	220	150	1	267	24	12	301	24	6	42
2,000	1256	112	283	37	15	37	195	15	252	116	2	389	28	14	290	33	31	62
3,000	1136	183	217	10	7	18	158	8	223	140	0	378	50	21	187	22	25	104
4,000	1190	309	198	6	4	6	250	2	181	110	0	377	15	38	170	24	19	93
6,000	1116	319	132	0	12	2	339	2	86	59	0	362	34	14	135	8	31	48
8,000	528	161	48	1	5	1	141	0	30	28	0	218	14	7	65	1	18	18
12,000	396	112	55	0	6	1	48	0	6	2	0	170	13	6	44	0	12	11
17,000	136	23	42	0	3	0	3	0	2	0	0	63	8	5	16	0	1	7
17,000+	80	16	40	0	0	0	0	0	0	0	0	18	4	4	6	0	0	8
Total	8304	1444	1493	188	83	254	1672	56	1343	820	13	2519	215	135	1668	136	146	414

Table 7: Percent Utilization for distance inland (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database.

Distance Inland (m)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	*Neritina vespertina*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
250	9.2	3.7	12.2	45.7	10.8	45.3	8.0	32.1	14.4	12.2	76.9	4.4	7.4	5.2	16.2	11.0	1.4	1.9
500	7.9	3.8	7.0	12.8	10.8	15.7	9.2	1.8	11.2	14.0	0.0	6.6	4.2	5.2	11.0	6.6	0.7	3.1
1,000	12.6	7.0	12.8	12.8	15.7	13.4	15.0	17.9	16.4	18.3	7.7	10.6	11.2	8.9	18.0	17.6	4.1	10.1
2,000	15.1	7.8	19.0	19.7	18.1	14.6	11.7	26.8	18.8	14.1	15.4	15.4	13.0	10.4	17.4	24.3	21.2	15.0
3,000	13.7	12.7	14.5	5.3	8.4	7.1	9.4	14.3	16.6	17.1	0.0	15.0	23.3	15.6	11.2	16.2	17.1	25.1
4,000	14.3	21.4	13.3	3.2	4.8	2.4	15.0	3.6	13.5	13.4	0.0	15.0	7.0	28.1	10.2	17.6	13.0	22.5
6,000	13.4	22.1	8.8	0.0	14.5	0.8	20.3	3.6	6.4	7.2	0.0	14.4	15.8	10.4	8.1	5.9	21.2	11.6
8,000	6.4	11.1	3.2	0.5	6.0	0.4	8.4	0.0	2.2	3.4	0.0	8.7	6.5	5.2	3.9	0.7	12.3	4.3
12,000	4.8	7.8	3.7	0.0	7.2	0.4	2.9	0.0	0.4	0.2	0.0	6.7	6.0	4.4	2.6	0.0	8.2	2.7
17,000	1.6	1.6	2.8	0.0	3.6	0.0	0.2	0.0	0.1	0.0	0.0	2.5	3.7	3.7	1.0	0.0	0.7	1.7
17,000+	1.0	1.1	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.9	3.0	0.4	0.0	0.0	1.9

Table 8: Standardized suitability for distance inland (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database. Standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Distance Inland (m)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	*Neritina vespertina*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
250	1	0.23	0.48	1.00	0.53	1.00	0.58	1.00	1.00	0.74	1.00	0.31	0.36	0.18	1.00	0.75	0.08	0.10
500	1	0.28	0.32	0.33	0.62	0.41	0.78	0.06	0.91	1.00	0.00	0.55	0.23	0.21	0.80	0.52	0.04	0.20
1,000	1	0.32	0.36	0.20	0.56	0.21	0.78	0.40	0.83	0.81	0.07	0.55	0.39	0.23	0.81	0.87	0.17	0.40
2,000	1	0.29	0.45	0.26	0.54	0.20	0.51	0.51	0.79	0.52	0.12	0.67	0.38	0.22	0.65	1.00	0.72	0.49
3,000	1	0.53	0.38	0.08	0.28	0.11	0.46	0.30	0.78	0.70	0.00	0.72	0.75	0.37	0.47	0.74	0.65	0.92
4,000	1	0.85	0.33	0.04	0.15	0.03	0.69	0.07	0.60	0.52	0.00	0.68	0.21	0.64	0.40	0.77	0.47	0.78
6,000	1	0.94	0.24	0.00	0.49	0.01	1.00	0.08	0.30	0.30	0.00	0.70	0.52	0.25	0.34	0.27	0.81	0.43
8,000	1	1.00	0.18	0.02	0.43	0.01	0.88	0.00	0.22	0.30	0.00	0.89	0.45	0.27	0.35	0.07	1.00	0.34
12,000	1	0.93	0.28	0.00	0.69	0.02	0.40	0.00	0.06	0.03	0.00	0.93	0.56	0.30	0.31	0.00	0.89	0.28
17,000	1	0.55	0.62	0.00	1.00	0.00	0.07	0.00	0.06	0.00	0.00	1.00	1.00	0.74	0.33	0.00	0.22	0.51
17,000+	1	0.66	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.85	1.00	0.21	0.00	0.00	1.00

Table 9: Smoothed standardized suitability for distance inland (m) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database. Smoothed standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Distance Inland (m)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	*Neritina vespertina*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
250	1	0.25	0.40	0.66	0.58	0.70	0.68	0.53	0.95	0.87	0.50	0.43	0.30	0.20	0.90	0.64	0.06	0.15
500	1	0.27	0.39	0.51	0.57	0.54	0.71	0.49	0.91	0.85	0.36	0.47	0.33	0.21	0.87	0.71	0.10	0.23
1,000	1	0.29	0.38	0.26	0.58	0.27	0.69	0.32	0.84	0.78	0.06	0.59	0.33	0.22	0.75	0.80	0.31	0.36
2,000	1	0.38	0.40	0.18	0.46	0.17	0.58	0.40	0.80	0.68	0.06	0.65	0.51	0.27	0.64	0.87	0.51	0.60
3,000	1	0.56	0.39	0.13	0.32	0.11	0.55	0.29	0.72	0.58	0.04	0.69	0.45	0.41	0.51	0.83	0.61	0.73
4,000	1	0.77	0.32	0.04	0.31	0.05	0.72	0.15	0.56	0.51	0.00	0.70	0.49	0.42	0.40	0.59	0.64	0.71
6,000	1	0.93	0.25	0.02	0.36	0.02	0.86	0.05	0.38	0.38	0.00	0.76	0.39	0.38	0.36	0.37	0.76	0.52
8,000	1	0.95	0.23	0.01	0.53	0.01	0.76	0.03	0.20	0.21	0.00	0.84	0.51	0.27	0.33	0.11	0.90	0.35
12,000	1	0.83	0.36	0.01	0.71	0.01	0.45	0.00	0.11	0.11	0.00	0.94	0.67	0.43	0.33	0.02	0.70	0.38
17,000	1	0.71	0.63	0.00	0.56	0.01	0.16	0.00	0.04	0.01	0.00	0.80	0.80	0.68	0.29	0.00	0.37	0.60
17,000+	1	0.61	0.81	0.00	0.50	0.00	0.04	0.00	0.03	0.00	0.00	0.74	0.93	0.87	0.27	0.00	0.11	0.76

Table 10: Frequency of occurrence for maximum downstream slope (m rise /m run) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database.

Maximum Downstream Slope	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
0.1	1177	44	237	59	21	99	15	24	205	37	459	55	25	140	75	35	142
0.2	1189	81	263	63	15	83	50	17	195	78	399	38	16	293	25	32	103
0.3	941	175	200	20	6	29	140	6	168	102	265	29	8	173	21	29	28
0.4	728	98	145	13	12	13	119	2	130	99	249	26	6	197	2	15	28
0.5	1160	96	298	22	16	15	447	2	201	230	263	15	7	490	6	13	16
0.6	442	79	93	3	2	7	110	2	58	59	170	14	8	89	3	1	17
0.7	259	32	40	3	1	5	58	1	46	33	91	3	3	57	3	3	10
0.8	283	69	21	1	0	1	75	0	48	27	81	20	9	47	0	9	3
0.9	254	46	34	2	0	1	68	0	75	44	76	3	2	28	0	3	0
1	421	148	75	2	1	1	157	0	30	23	98	3	1	31	1	3	3
2	1171	379	85	0	3	0	425	2	166	86	301	5	15	121	0	2	10
3	242	170	2	0	3	0	7	0	7	1	60	4	35	2	0	1	54
3+	37	27	0	0	3	0	1	0	14	1	7	0	0	0	0	0	0
Total	8304	1444	1493	188	83	254	1672	56	1343	820	2519	215	135	1668	136	146	414

Table 11: Percent Utilization for maximum downstream slope (m rise /m run) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database.

Maximum Downstream Slope	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
0.1	14.2	3.0	15.9	31.4	25.3	39.0	0.9	42.9	15.3	4.5	18.2	25.6	18.5	8.4	55.1	24.0	34.3
0.2	14.3	5.6	17.6	33.5	18.1	32.7	3.0	30.4	14.5	9.5	15.8	17.7	11.9	17.6	18.4	21.9	24.9
0.3	11.3	12.1	13.4	10.6	7.2	11.4	8.4	10.7	12.5	12.4	10.5	13.5	5.9	10.4	15.4	19.9	6.8
0.4	8.8	6.8	9.7	6.9	14.5	5.1	7.1	3.6	9.7	12.1	9.9	12.1	4.4	11.8	1.5	10.3	6.8
0.5	14.0	6.6	20.0	11.7	19.3	5.9	26.7	3.6	15.0	28.0	10.4	7.0	5.2	29.4	4.4	8.9	3.9
0.6	5.3	5.5	6.2	1.6	2.4	2.8	6.6	3.6	4.3	7.2	6.7	6.5	5.9	5.3	2.2	0.7	4.1
0.7	3.1	2.2	2.7	1.6	1.2	2.0	3.5	1.8	3.4	4.0	3.6	1.4	2.2	3.4	2.2	2.1	2.4
0.8	3.4	4.8	1.4	0.5	0.0	0.4	4.5	0.0	3.6	3.3	3.2	9.3	6.7	2.8	0.0	6.2	0.7
0.9	3.1	3.2	2.3	1.1	0.0	0.4	4.1	0.0	5.6	5.4	3.0	1.4	1.5	1.7	0.0	2.1	0.0
1	5.1	10.2	5.0	1.1	1.2	0.4	9.4	0.0	2.2	2.8	3.9	1.4	0.7	1.9	0.7	2.1	0.7
2	14.1	26.2	5.7	0.0	3.6	0.0	25.4	3.6	12.4	10.5	11.9	2.3	11.1	7.3	0.0	1.4	2.4
3	2.9	11.8	0.1	0.0	3.6	0.0	0.4	0.0	0.5	0.1	2.4	1.9	25.9	0.1	0.0	0.7	13.0
3+	0.4	1.9	0.0	0.0	3.6	0.0	0.1	0.0	1.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0

Table 12: Standardized suitability for maximum downstream slope (m rise /m run) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database. Standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Maximum Downstream Slope	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
0.1	1.00	0.05	0.78	0.95	0.22	1.00	0.03	1.00	0.46	0.16	1.00	0.66	0.15	0.28	1.00	0.94	0.54
0.2	1.00	0.09	0.86	1.00	0.16	0.83	0.11	0.70	0.43	0.33	0.86	0.45	0.09	0.58	0.33	0.85	0.39
0.3	1.00	0.25	0.83	0.40	0.08	0.37	0.39	0.31	0.47	0.55	0.72	0.44	0.06	0.44	0.35	0.97	0.13
0.4	1.00	0.18	0.78	0.34	0.20	0.21	0.42	0.13	0.47	0.69	0.88	0.51	0.06	0.64	0.04	0.65	0.17
0.5	1.00	0.11	1.00	0.36	0.17	0.15	1.00	0.08	0.46	1.00	0.58	0.18	0.04	1.00	0.08	0.35	0.06
0.6	1.00	0.24	0.82	0.13	0.06	0.19	0.65	0.22	0.35	0.67	0.99	0.45	0.13	0.48	0.11	0.07	0.17
0.7	1.00	0.17	0.60	0.22	0.05	0.23	0.58	0.19	0.47	0.64	0.90	0.16	0.08	0.52	0.18	0.36	0.17
0.8	1.00	0.33	0.29	0.07	0.00	0.04	0.69	0.00	0.45	0.48	0.73	1.00	0.22	0.39	0.00	1.00	0.05
0.9	1.00	0.25	0.52	0.15	0.00	0.05	0.69	0.00	0.78	0.87	0.77	0.17	0.05	0.26	0.00	0.37	0.00
1	1.00	0.48	0.69	0.09	0.03	0.03	0.97	0.00	0.19	0.28	0.60	0.10	0.02	0.17	0.04	0.22	0.03
2	1.00	0.44	0.28	0.00	0.03	0.00	0.94	0.08	0.37	0.37	0.66	0.06	0.09	0.24	0.00	0.05	0.04
3	1.00	0.96	0.03	0.00	0.15	0.00	0.08	0.00	0.08	0.02	0.64	0.23	1.00	0.02	0.00	0.13	1.00
3+	1.00	1.00	0.00	0.00	1.00	0.00	0.07	0.00	1.00	0.14	0.49	0.00	0.00	0.00	0.00	0.00	0.00

Table 13: Smoothed standardized suitability for maximum downstream slope (m rise /m run) by the species that occurred in at least 50 different survey sites within the DAR Aquatic Surveys Database. Smoothed standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Maximum Downstream Slope	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Tilapia sp.*	*Xiphophorus helleri*
0.1	1.00	0.07	0.82	0.97	0.19	0.91	0.07	0.85	0.45	0.24	0.93	0.56	0.12	0.43	0.66	0.89	0.46
0.2	1.00	0.13	0.82	0.78	0.15	0.73	0.18	0.67	0.46	0.35	0.86	0.52	0.10	0.43	0.56	0.92	0.35
0.3	1.00	0.18	0.82	0.58	0.15	0.47	0.31	0.38	0.46	0.52	0.82	0.46	0.07	0.55	0.24	0.82	0.23
0.4	1.00	0.18	0.87	0.37	0.15	0.24	0.60	0.18	0.47	0.74	0.73	0.37	0.05	0.69	0.16	0.66	0.12
0.5	1.00	0.18	0.86	0.27	0.14	0.18	0.69	0.15	0.43	0.79	0.81	0.38	0.07	0.71	0.08	0.36	0.14
0.6	1.00	0.18	0.81	0.23	0.09	0.19	0.74	0.17	0.42	0.77	0.82	0.27	0.08	0.67	0.12	0.26	0.14
0.7	1.00	0.25	0.57	0.14	0.03	0.15	0.64	0.14	0.42	0.60	0.87	0.54	0.14	0.46	0.10	0.48	0.13
0.8	1.00	0.25	0.47	0.14	0.02	0.11	0.65	0.06	0.57	0.67	0.80	0.44	0.12	0.39	0.06	0.58	0.07
0.9	1.00	0.35	0.50	0.10	0.01	0.04	0.78	0.00	0.47	0.54	0.70	0.42	0.10	0.28	0.01	0.53	0.03
1	1.00	0.39	0.50	0.08	0.02	0.03	0.87	0.03	0.45	0.51	0.67	0.11	0.05	0.23	0.01	0.22	0.02
2	1.00	0.63	0.34	0.03	0.07	0.01	0.66	0.03	0.21	0.22	0.63	0.13	0.37	0.15	0.01	0.14	0.36
3	1.00	0.80	0.10	0.00	0.39	0.00	0.36	0.03	0.48	0.18	0.59	0.10	0.36	0.09	0.00	0.06	0.35
3+	1.00	0.98	0.02	0.00	0.58	0.00	0.07	0.00	0.54	0.08	0.56	0.12	0.50	0.01	0.00	0.06	0.50

Awaous guamensis:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

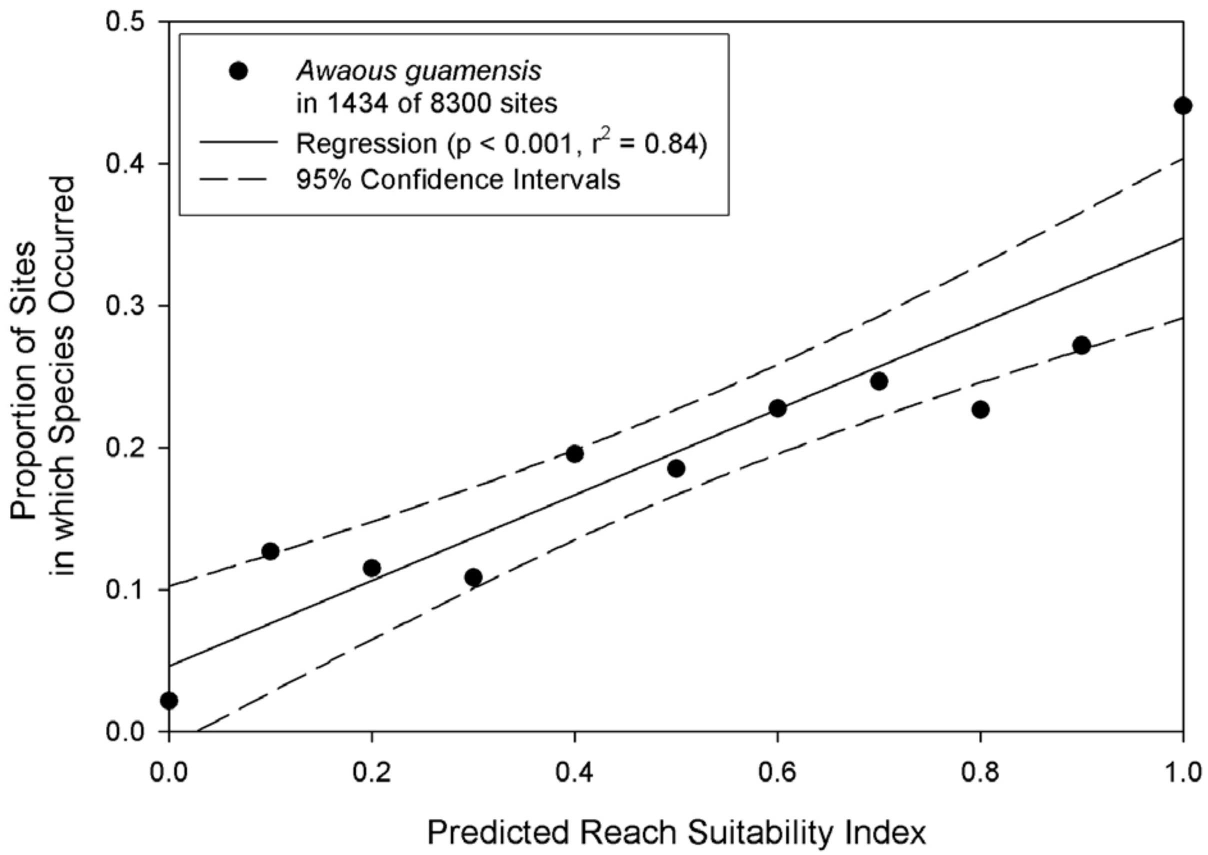

Figure 46: Proportion of the total sites where *Awaous guamensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Awaous guamensis*.

Lentipes concolor:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

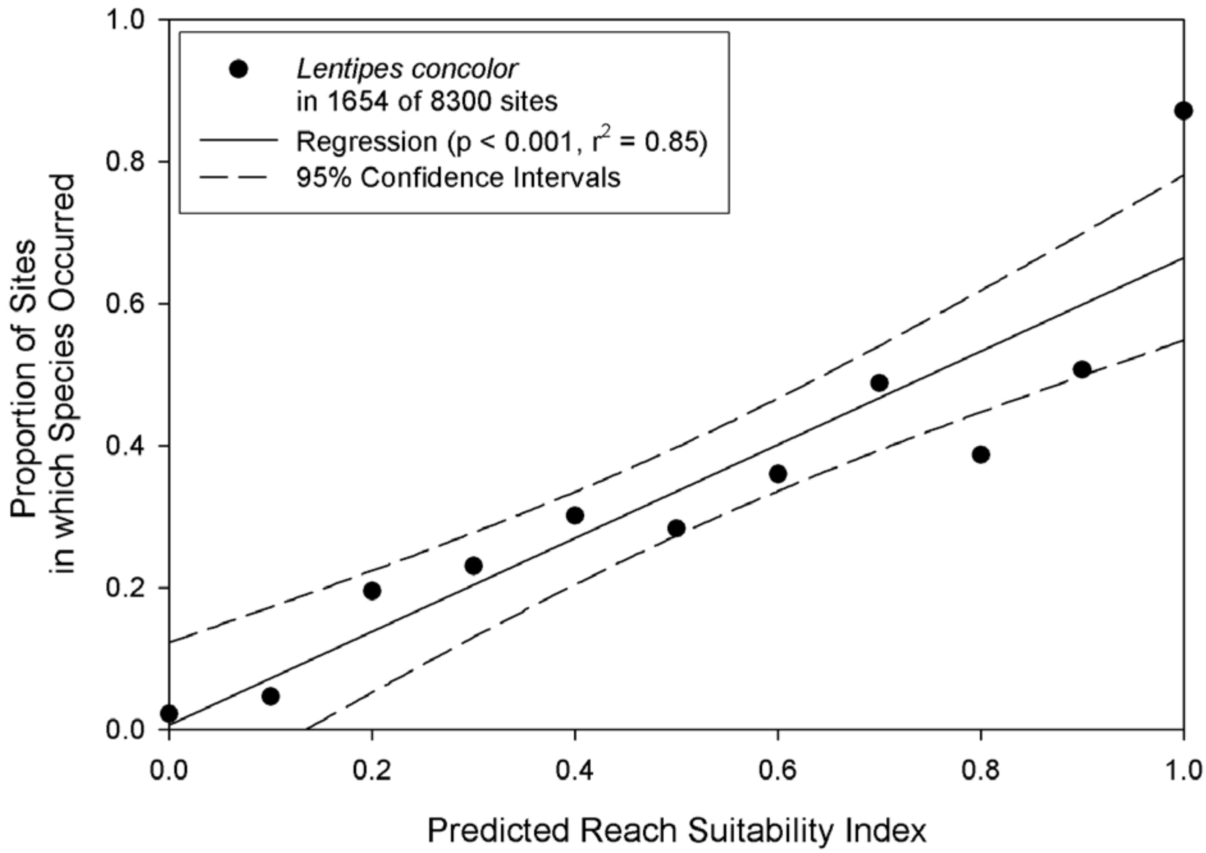

Figure 47: Proportion of the total sites where *Lentipes concolor* was observed within each 0.1 group of the Reach Suitability Index equation for *Lentipes concolor*.

Sicyopterus stimpsoni:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

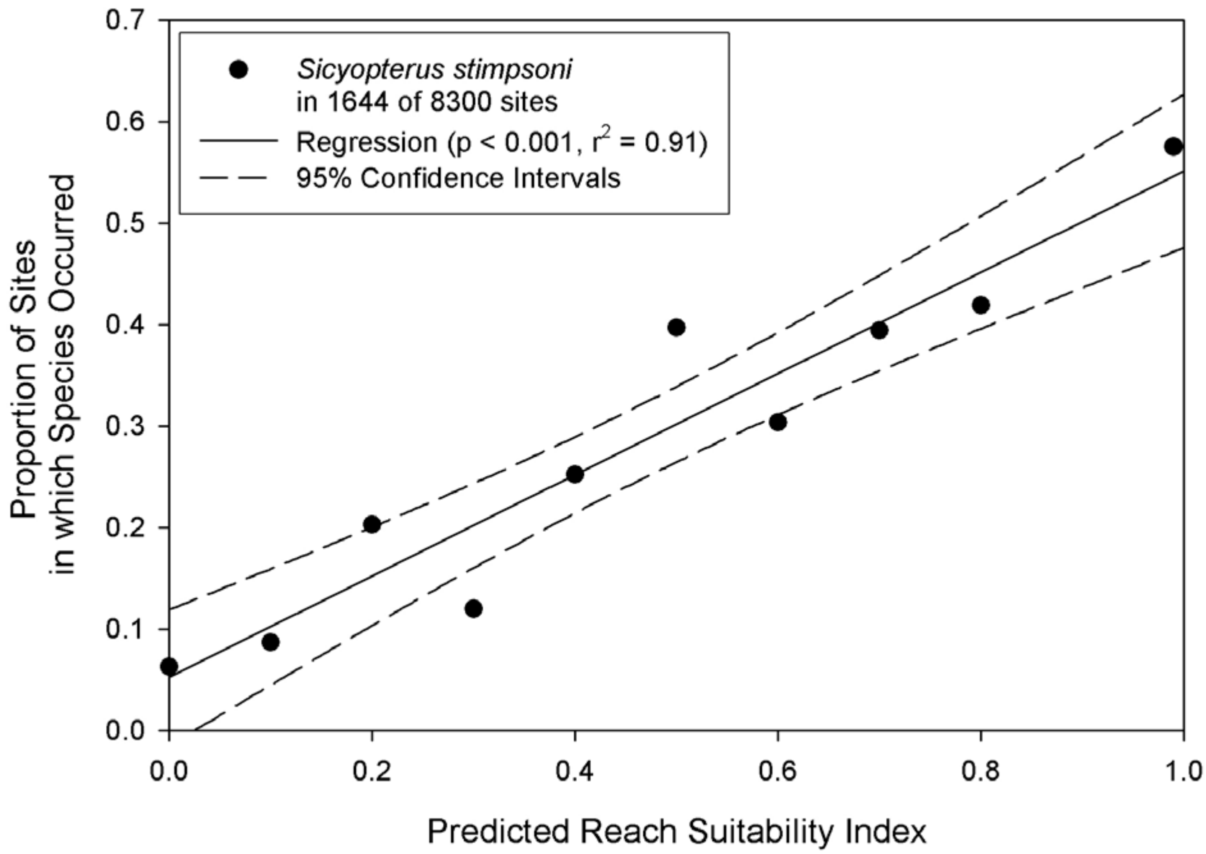

Figure 48: Proportion of the total sites where *Sicyopterus stimpsoni* was observed within each 0.1 group of the Reach Suitability Index equation for *Sicyopterus stimpsoni*.

Stenogobius hawaiiensis:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

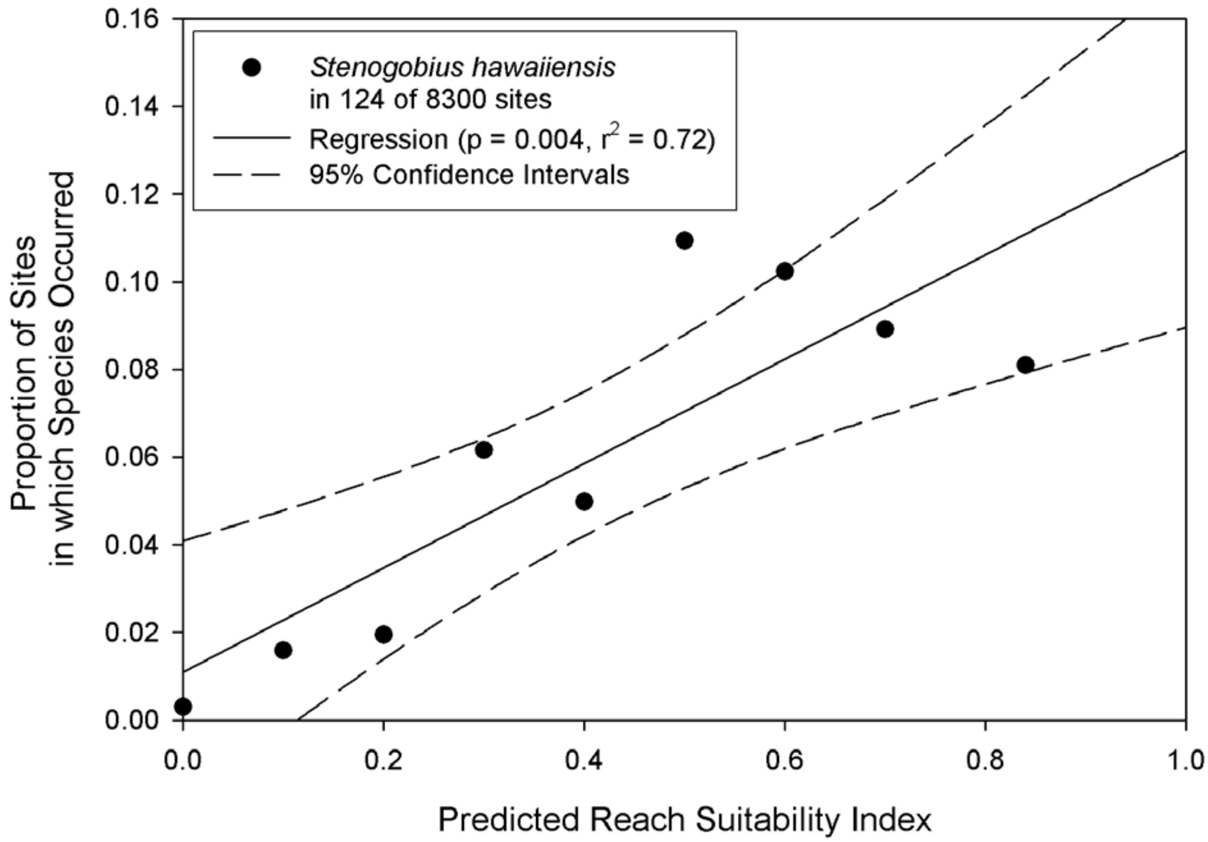

Figure 49: Proportion of the total sites where *Stenogobius hawaiiensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Stenogobius hawaiiensis*.

Eleotris sandwicensis:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

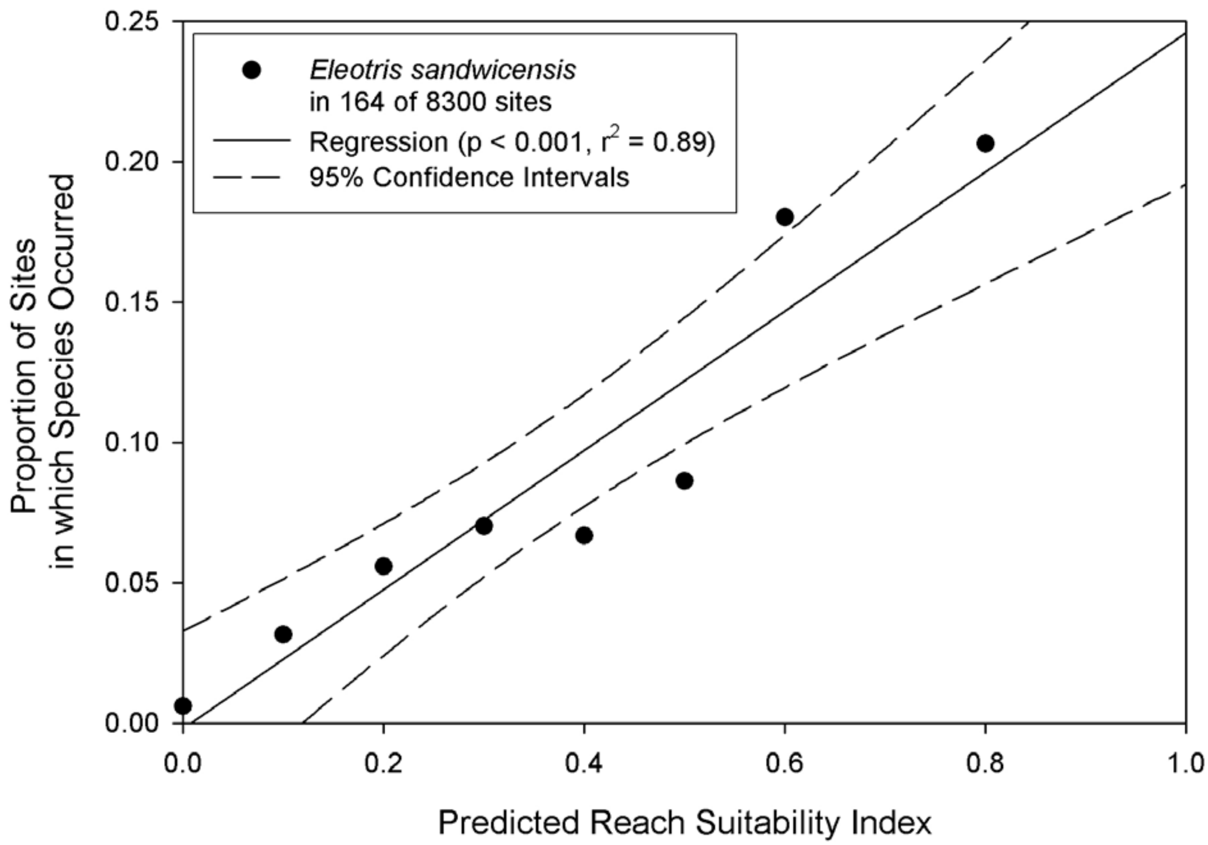

Figure 50: Proportion of the total sites where *Eleotris sandwicensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Eleotris sandwicensis*.

Neritina granosa:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

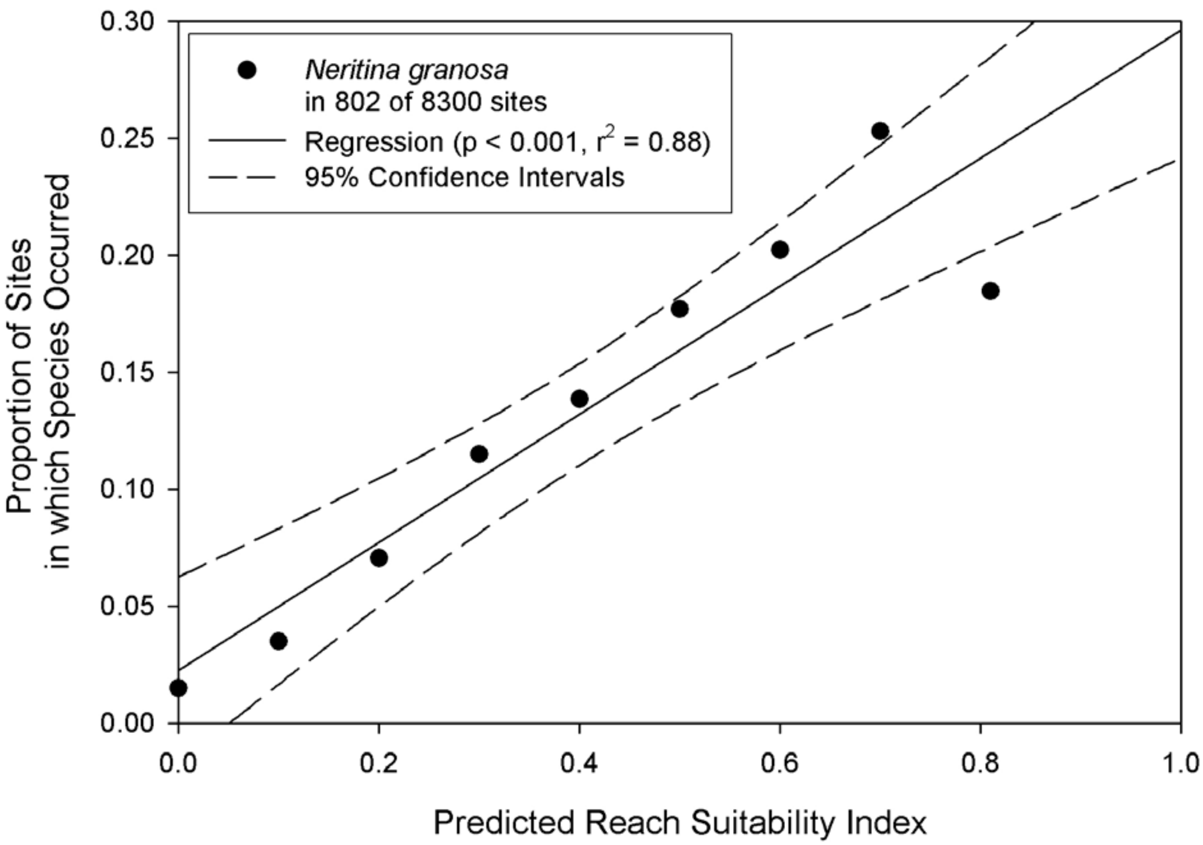

Figure 51: Proportion of the total sites where *Neritina granosa* was observed within each 0.1 group of the Reach Suitability Index equation for *Neritina granosa*.

Atyoida bisulcata:

The most appropriate relationship was:

1. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability)

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

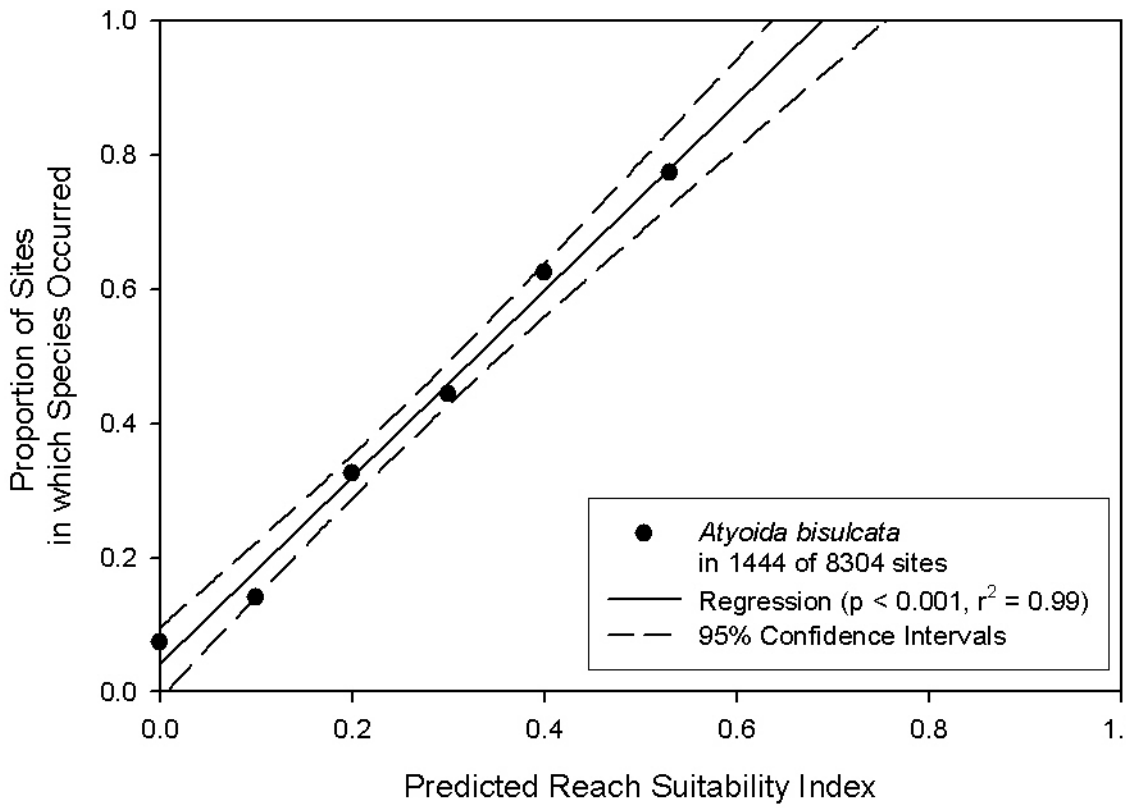

Figure 52: Proportion of the total sites where *Atyoida bisulcata* was observed within each 0.1 group of the Reach Suitability Index equation for *Atyoida bisulcata*.

Macrobrachium grandimanus:

The most appropriate relationship was:

1. Reach Suitability = (Elevation Suitability + Distance Inland Suitability + Downstream Barrier Height Suitability)

where: if Elevation Suitability or Distance Inland Suitability or Downstream Barrier Height Suitability = 0, then Reach Suitability = 0

Both relationships had adequate distributions and the equation with the higher r^2 was selected.

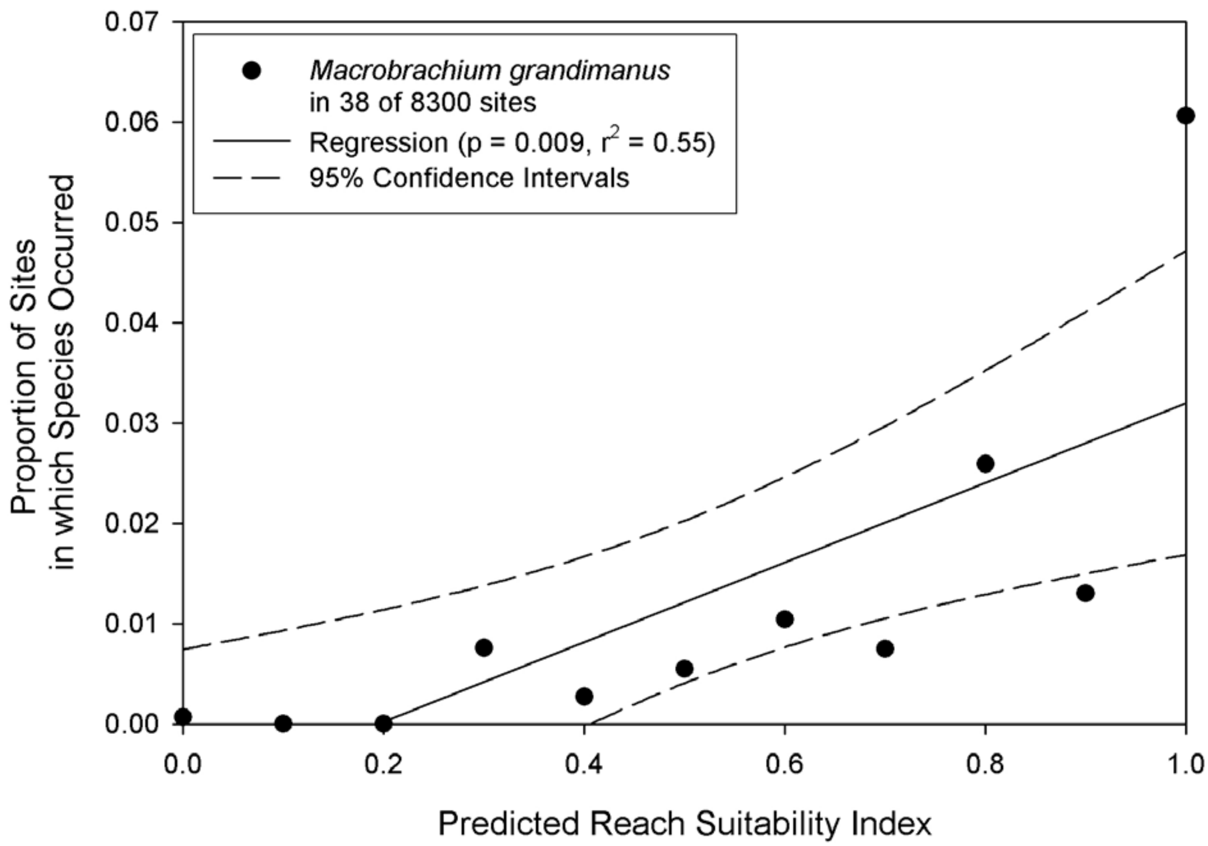

Figure 53: Proportion of the total sites where *Macrobrachium grandimanus* was observed within each 0.1 group of the Reach Suitability Index equation for *Macrobrachium grandimanus*.

Appendix 3: Site Scale Metrics

All data reflected in this report came from the DAR Aquatic Surveys Database. The data for the habitat level variables of habitat type, depth, substrate, and temperature were gathered from DAR point quadrat survey data within the DAR Aquatic Surveys Database as these surveys consistently used the same methodology to collect these habitat variables.

Following an identical process to developing suitability criteria for the instream distribution variables, suitability was determined for site scale metrics. To compare the suitability for the stream animals, availability, utilization, and suitability criteria were developed following standardized procedures (Bovee and Cochnauer 1977). In general, this method bases habitat utilization on the presence/absence data and does not take into account site density. Habitat availability is the frequency of each habitat category and is based on the distribution of habitats observed in the field survey. Percent availability is calculated by dividing the number of observations for a habitat category by the total number of observations and multiplying by 100. Utilization is the frequency of occurrence for an individual species in each habitat category. Percent utilization is calculated by dividing the number of sites with a species observed for a habitat category by the total number of sites with a species observed and multiplying by 100. Suitability is developed by dividing the percent utilization for each habitat category with the percent availability for each habitat category. The standardized suitability has the range adjusted so that the largest value for each species equals 1 (highly suitable) and the lowest value equals 0 (unsuitable). The smoothed standardized suitability was created by averaging the value for the bin with its two nearest neighbors. In the case of the first and last bin values, they were only averaged with the single bin next to them. The smoothed suitability was used to decrease the variation between adjacent bins as a result of same size or sample distribution. Non-ordinal categorical suitability criteria (e.g., habitat types) were not smoothed.

The decision on the bin sizes for the various continuous variables was set subjectively to balance several factors. First, the number of samples in each bin attempted to have at least 200 observations from the total number of samples. Next, the bin sizes were adjusted to make the number of samples in each bin as consistent as possible, and finally, the bins were distributed to fit the field survey data. For example, the HDSS technique classified depth into specific depth categories. In this case, the field depth categories were used to most closely match survey information.

To combine the various site scale variables into an overall suitability score for the site the following process is followed. Data from field surveys are used to characterize local habitat. Typical data collected during field surveys can be divided into two broad categories. First are those descriptive variables that differentiate natural habitat into more or less suitable units. For example, habitat type classifications into riffle runs or pools or depth classification from shallow to deep are good examples of differentiation of natural habitat into different units. The second type of descriptive variables is those variables that describe some level of human modification to natural habitats. For example, the extent of channelization or presence of flood control structures occurring at a site modifies what natural habitat would be normally expected to be found at the location. So in general, first we calculate the natural conditions at a site and then score for the natural condition is modified by downward by extent of human modification at the site.

For native amphidromous animals found in Hawaiian streams, we typically describe habitat with respect to variables associated with habitat type, depth, substrate, water velocity, water quality, bank and riparian condition to describe the natural stream habitats. Not all surveys of stream habitat record all of these variables. Habitat type, depth, substrate, water quality, bank and riparian conditions form the core descriptors stream animal habitat using the HDSS techniques. At a single location a linear combination of the suitability for each of the five variables is used to provide an overall suitability score. The combination would be the suitability for each score added together and divided by the total number of variables. This approach allows some flexibility to utilize the variables are collected during field sampling.

The next set of variables are associated with human modification of the environment include channel type, substrate embeddedness, or other human modifications of the environment that may be recorded during surveys. These variables modify the natural habitat variables described above. For example, cobble may be the primary substrate, but if it is highly embedded with fine sediment than it is less suitable than non-embedded cobble substrate. Not all variables will have a modifier variable.

The overall site impact score calculation is defined in advance and is applied identically to all sites within the HSHEP model. So while some variables may or may not occur in a specific application of an HSHEP model, within a specific application of the model all variables will be consistently applied.

For the application of the HSHEP model within the Ala Wai watershed streams, the variable combination calculations are as follows:

Site Suitability Equation for each species is –

$$(HV_1 * MV_1 + HV_2 * MV_2 + \cdots HV_n * MV_n)/n$$

where habitat variables (HV) and associated Modifier Variables (MV) are shown below:

Area	**Habitat Variable**	**Modifier Variable**
Habitat Type	Habitat Type	Channel Condition
Substrate	Substrate	Embeddedness
Depth	Depth	
Water Quality	Threshold limits for Temperature, Dissolved Oxygen, pH, Conductivity	
Bank & Riparian Condition	(Bank Height + Bank Angle + Surface Protection + Riparian Condition)/4	

Change as a result of an instream alteration (either negative or positive) in physical habitat, water quantity or water quality that will need to be able to be measured by one of the habitat or modifier variables to be able to quantify habitat changes in a HSHEP model.

Note to reviewer: The data for the site variables shown below are being updated to reflect the latest information within the DAR Aquatic Surveys Database but provide a good example of the data and the approach.

Table 14: Frequency, percent utilization, and standardized suitability for the use of habitat types by the species that occurred in at least 50 different survey sites within the DAR Point Quadrat Surveys. Colors in the standardized suitability reflect three groups to aid in interpreting the data. Standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green. No smoothed standardized suitability values are presented as the habitat types are categorical variables.

	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Gambusia affinis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Xiphophorus helleri*
Frequency															
Cascade	84	11	7	0	0	0	17	12	18	35	0	0	13	0	1
Riffle	1076	162	138	13	1	18	223	131	170	354	10	2	307	7	14
Run	3216	505	587	66	15	134	734	486	359	863	57	23	780	75	158
Pool	1605	279	320	28	28	43	374	358	127	429	55	23	209	21	105
Plunge Pool	213	67	33	6	1	1	64	40	42	37	0	5	44	0	6
Side Pool	649	97	111	14	10	20	101	132	43	217	21	2	99	9	33
Total	6843	1121	1196	127	55	216	1513	1159	759	1935	143	55	1452	112	317
Percent Utilization															
Cascade	1.2	1.0	0.6	0.0	0.0	0.0	1.1	1.0	2.4	1.8	0.0	0.0	0.9	0.0	0.3
Riffle	15.7	14.5	11.5	10.2	1.8	8.3	14.7	11.3	22.4	18.3	7.0	3.6	21.1	6.3	4.4
Run	47.0	45.0	49.1	52.0	27.3	62.0	48.5	41.9	47.3	44.6	39.9	41.8	53.7	67.0	49.8
Pool	23.5	24.9	26.8	22.0	50.9	19.9	24.7	30.9	16.7	22.2	38.5	41.8	14.4	18.8	33.1
Plunge Pool	3.1	6.0	2.8	4.7	1.8	0.5	4.2	3.5	5.5	1.9	0.0	9.1	3.0	0.0	1.9
Side Pool	9.5	8.7	9.3	11.0	18.2	9.3	6.7	11.4	5.7	11.2	14.7	3.6	6.8	8.0	10.4
Standardized Suitability															
Cascade	1	0.42	0.42	0.00	0.00	0.00	0.67	0.64	1.00	1.00	0.00	0.00	0.54	0.00	0.18
Riffle	1	0.48	0.64	0.43	0.05	0.40	0.69	0.55	0.74	0.79	0.27	0.08	1.00	0.28	0.20
Run	1	0.50	0.92	0.73	0.27	1.00	0.76	0.68	0.52	0.64	0.52	0.30	0.85	1.00	0.75
Pool	1	0.55	1.00	0.62	1.00	0.64	0.78	1.00	0.37	0.64	1.00	0.61	0.46	0.56	1.00
Plunge Pool	1	1.00	0.78	1.00	0.27	0.11	1.00	0.84	0.92	0.42	0.00	1.00	0.72	0.00	0.43
Side Pool	1	0.48	0.86	0.77	0.88	0.74	0.52	0.91	0.31	0.80	0.94	0.13	0.53	0.59	0.78

Table 15: Frequency of occurrence, percent utilization, standardized suitability, and adjusted smoothed standardized suitability for site depth (in.) for native amphidromous animals in different survey sites within the DAR Point Quadrat Surveys. The *values were adjusted to further smooth the results with unadjusted smoothed results in parentheses.

Depth Bin (in)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Lentipes concolor*	*Macrobrachium grandimanus*	*Neritina granosa*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*
Frequency									
0	27	0	0	0	0	0	0	0	0
3	210	9	9	1	11	0	3	6	4
6	500	50	32	4	20	3	8	16	9
12	1742	273	216	19	275	5	152	296	29
24	2503	442	500	46	584	13	295	629	48
36	786	123	191	27	226	2	85	203	10
>36	315	51	71	14	74	3	33	46	11
Total	6083	948	1019	111	1190	26	576	1196	111
Percent Utilization									
0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	3.5	0.9	0.9	0.9	0.9	0.0	0.5	0.5	3.6
6	8.2	5.3	3.1	3.6	1.7	11.5	1.4	1.3	8.1
12	28.6	28.8	21.2	17.1	23.1	19.2	26.4	24.7	26.1
24	41.1	46.6	49.1	41.4	49.1	50.0	51.2	52.6	43.2
36	12.9	13.0	18.7	24.3	19.0	7.7	14.8	17.0	9.0
>36	5.2	5.4	7.0	12.6	6.2	11.5	5.7	3.8	9.9
Total	100	100	100	100	100	100	100	100	100
Standardized Suitability									
0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1	0.3	0.3	0.3	0.3	0.0	0.2	0.1	1.0
6	1	0.6	0.4	0.4	0.2	1.4	0.2	0.2	1.0
12	1	1.0	0.7	0.6	0.8	0.7	0.9	0.9	0.9
24	1	1.1	1.2	1.0	1.2	1.2	1.2	1.3	1.1
36	1	1.0	1.5	1.9	1.5	0.6	1.1	1.3	0.7
>36	1	1.0	1.3	2.4	1.2	2.2	1.1	0.7	1.9
Max	1	1.1	1.5	2.4	1.5	2.2	1.2	1.3	1.9
Adjusted Smoothed Standardized Suitability									
0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1	0.2	0.2	0.1	0.2	0.0	0.1	0.1	0.5
6	1	0.6	0.3	0.2	0.1	0.5*(0.6)	0.1	0.1	0.5
12	1	0.9	0.5	0.2	0.5	0.5*(0.3)	0.7	0.7	0.5
24	1	1.0	0.8	0.4	0.8	0.5	1.0	1.0	0.5
36	1	0.9	1.0	0.8	1.0	0.5*(0.3)	0.9	1.0	0.5*(0.4)
>36	1	0.9	0.9	1.0	0.8	1.0	0.9	0.6	1.0

Table 16: Percent Utilization for site substrate and total samples by the species that occurred in at least 50 different survey sites within the DAR Point Quadrat Surveys.

	all sites	no species observed	*Lentipes concolor*	*Sicyopterus stimpsoni*	*Macrobrachium lar*	*Awaous guamensis*	*Atyoida bisulcata*	*Neritina granosa*	*Xiphophorus helleri*	*Kuhlia xenura*	*Poecilia reticulata*	*Eleotris sandwicensis*	*Stenogobius hawaiiensis*	*Gambusia affinis*	*Procambarus clarkii*
Detritus	1.2	1.5	0.2	0.2	1.8	0.6	0.5	0.3	2.7	1.4	3.6	2.8	2.6	2.5	1.9
Fine Sediment	6.5	5.8	8.4	7.2	7.4	9.3	4.3	4.4	5.1	6.2	11.5	6.4	7.6	6.0	2.9
Sand	3.5	3.5	1.1	2.0	3.8	5.7	0.9	1.7	6.4	6.0	6.0	6.1	23.6	8.4	3.6
Gravel	12.2	14.8	7.0	7.8	12.8	12.3	7.4	8.0	23.7	13.8	19.3	13.9	14.9	12.2	20.5
Cobble	29.5	29.0	30.7	35.5	28.1	30.2	29.4	28.6	29.3	33.4	18.5	35.7	31.4	30.0	32.7
Boulder	32.8	29.6	35.5	39.1	34.8	34.3	33.9	42.6	28.0	36.5	29.0	31.0	19.9	19.1	32.3
Bedrock	14.3	15.9	17.0	8.1	11.3	7.7	23.5	14.4	4.9	2.7	12.1	4.1	0.0	21.8	6.2
Total Samples	6999	2156	1445	1438	1156	1156	1087	757	315	187	146	123	111	56	52

Table 17: Standardized suitability for site substrate by the species that occurred in at least 50 different survey sites within the DAR Point Quadrat Surveys. Standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

	all sites	no species observed	*Lentipes concolor*	*Sicyopterus stimpsoni*	*Macrobrachium lar*	*Awaous guamensis*	*Atyoida bisulcata*	*Neritina granosa*	*Xiphophorus helleri*	*Kuhlia xenura*	*Poecilia reticulata*	*Eleotris sandwicensis*	*Stenogobius hawaiiensis*	*Gambusia affinis*	*Procambarus clarkii*
Detritus	1	1.00	0.13	0.13	1.00	0.30	0.27	0.22	1.00	0.70	1.00	1.00	0.32	0.88	0.97
Fine Sediment	1	0.69	1.00	0.92	0.75	0.87	0.40	0.51	0.34	0.55	0.58	0.42	0.17	0.38	0.26
Sand	1	0.80	0.25	0.48	0.73	1.00	0.16	0.38	0.80	1.00	0.57	0.74	1.00	1.00	0.61
Gravel	1	0.95	0.45	0.53	0.69	0.61	0.37	0.50	0.84	0.65	0.53	0.48	0.18	0.41	1.00
Cobble	1	0.77	0.81	1.00	0.63	0.63	0.61	0.74	0.43	0.66	0.21	0.51	0.16	0.42	0.66
Boulder	1	0.71	0.84	0.99	0.71	0.64	0.63	1.00	0.37	0.65	0.29	0.40	0.09	0.24	0.59
Bedrock	1	0.87	0.92	0.47	0.53	0.33	1.00	0.78	0.15	0.11	0.28	0.12	0.00	0.63	0.26

Table 18: Smoothed standardized suitability for site substrate by the species that occurred in at least 50 different survey sites within the DAR Point Quadrat Surveys. Smoothed standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

	all sites	no species observed	*Lentipes concolor*	*Sicyopterus stimpsoni*	*Macrobrachium lar*	*Awaous guamensis*	*Atyoida bisulcata*	*Neritina granosa*	*Xiphophorus helleri*	*Kuhlia xenura*	*Poecilia reticulata*	*Eleotris sandwicensis*	*Stenogobius hawaiiensis*	*Gambusia affinis*	*Procambarus clarkii*
Detritus	1	0.85	0.56	0.52	0.88	0.59	0.34	0.37	0.67	0.62	0.79	0.71	0.25	0.63	0.62
Fine Sediment	1	0.83	0.46	0.51	0.83	0.72	0.28	0.37	0.71	0.75	0.72	0.72	0.50	0.75	0.62
Sand	1	0.81	0.57	0.64	0.73	0.83	0.31	0.46	0.66	0.74	0.56	0.54	0.45	0.60	0.63
Gravel	1	0.84	0.50	0.67	0.69	0.75	0.38	0.54	0.69	0.77	0.44	0.57	0.45	0.61	0.76
Cobble	1	0.81	0.70	0.84	0.68	0.63	0.54	0.75	0.55	0.65	0.34	0.46	0.14	0.36	0.75
Boulder	1	0.78	0.86	0.82	0.62	0.53	0.75	0.84	0.32	0.47	0.26	0.34	0.08	0.43	0.50
Bedrock	1	0.79	0.88	0.73	0.62	0.48	0.82	0.89	0.26	0.38	0.29	0.26	0.04	0.44	0.42

Table 19: Frequency of occurrence for site temperature (°C) by the species that occurred in at least 36 different survey sites within the DAR Point Quadrat Surveys.

Temp Bin (°C)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Xiphophorus helleri*
16	57	39	0	0	0	2	1	1	16	0	0	1	0	0
17	66	19	7	0	0	23	15	23	11	0	1	19	0	1
18	99	27	11	0	0	12	6	9	46	0	4	5	0	9
19	391	105	53	10	15	18	29	8	159	2	16	37	4	33
20	521	49	40	7	10	33	41	18	253	19	1	37	1	57
21	737	101	73	13	28	104	159	94	278	19	6	66	3	51
22	850	73	121	11	31	81	177	91	299	17	6	146	23	71
23	380	15	59	8	23	56	102	45	114	25	1	39	15	23
24	206	4	32	6	11	18	48	31	52	16	1	38	16	10
25	169	0	44	6	7	28	39	18	43	7	0	48	12	5
26	114	0	35	1	3	23	25	17	29	3	0	46	6	1
26+	81	0	35	10	6	13	15	9	10	1	0	26	10	0
Total	3671	432	510	72	134	411	657	364	1310	109	36	508	90	261

Table 20: Percent Utilization for site temperature (°C) by the species that occurred in at least 36 different survey sites within the DAR Point Quadrat Surveys.

Temp Bin (°C)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Xiphophorus helleri*
16	1.6	9.0	0.0	0.0	0.0	0.5	0.2	0.3	1.2	0.0	0.0	0.2	0.0	0.0
17	1.8	4.4	1.4	0.0	0.0	5.6	2.3	6.3	0.8	0.0	2.8	3.7	0.0	0.4
18	2.7	6.3	2.2	0.0	0.0	2.9	0.9	2.5	3.5	0.0	11.1	1.0	0.0	3.4
19	10.7	24.3	10.4	13.9	11.2	4.4	4.4	2.2	12.1	1.8	44.4	7.3	4.4	12.6
20	14.2	11.3	7.8	9.7	7.5	8.0	6.2	4.9	19.3	17.4	2.8	7.3	1.1	21.8
21	20.1	23.4	14.3	18.1	20.9	25.3	24.2	25.8	21.2	17.4	16.7	13.0	3.3	19.5
22	23.2	16.9	23.7	15.3	23.1	19.7	26.9	25.0	22.8	15.6	16.7	28.7	25.6	27.2
23	10.4	3.5	11.6	11.1	17.2	13.6	15.5	12.4	8.7	22.9	2.8	7.7	16.7	8.8
24	5.6	0.9	6.3	8.3	8.2	4.4	7.3	8.5	4.0	14.7	2.8	7.5	17.8	3.8
25	4.6	0.0	8.6	8.3	5.2	6.8	5.9	4.9	3.3	6.4	0.0	9.4	13.3	1.9
26	3.1	0.0	6.9	1.4	2.2	5.6	3.8	4.7	2.2	2.8	0.0	9.1	6.7	0.4
26+	2.2	0.0	6.9	13.9	4.5	3.2	2.3	2.5	0.8	0.9	0.0	5.1	11.1	0.0

Table 21: Standardized suitability for site temperature (°C) by the species that occurred in at least 36 different survey sites within the DAR Point Quadrat Surveys. Standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Temp Bin (°C)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Xiphophorus helleri*
16	1	1.00	0.00	0.00	0.00	0.10	0.07	0.05	0.58	0.00	0.00	0.04	0.00	0.00
17	1	0.42	0.25	0.00	0.00	1.00	0.85	1.00	0.34	0.00	0.37	0.71	0.00	0.14
18	1	0.40	0.26	0.00	0.00	0.35	0.23	0.26	0.96	0.00	0.99	0.13	0.00	0.83
19	1	0.39	0.31	0.21	0.52	0.13	0.28	0.06	0.84	0.07	1.00	0.23	0.08	0.77
20	1	0.14	0.18	0.11	0.26	0.18	0.29	0.10	1.00	0.47	0.05	0.18	0.02	1.00
21	1	0.20	0.23	0.14	0.51	0.40	0.80	0.37	0.78	0.33	0.20	0.22	0.03	0.63
22	1	0.13	0.33	0.10	0.49	0.27	0.78	0.31	0.72	0.26	0.17	0.43	0.22	0.76
23	1	0.06	0.36	0.17	0.82	0.42	1.00	0.34	0.62	0.85	0.06	0.25	0.32	0.55
24	1	0.03	0.36	0.24	0.72	0.25	0.87	0.43	0.52	1.00	0.12	0.46	0.63	0.44
25	1	0.00	0.60	0.29	0.56	0.48	0.86	0.31	0.52	0.53	0.00	0.70	0.58	0.27
26	1	0.00	0.71	0.07	0.36	0.58	0.82	0.43	0.52	0.34	0.00	1.00	0.43	0.08
26+	1	0.00	1.00	1.00	1.00	0.46	0.69	0.32	0.25	0.16	0.00	0.80	1.00	0.00

Table 22: Smoothed standardized suitability for site temperature (°C) by the species that occurred in at least 36 different survey sites within the DAR Point Quadrat Surveys. Smoothed standardized suitability values that were less than or equal to 0.33 were colored orange, those from 0.33 to less than or equal to 0.66 were colored yellow, and values greater than 0.66 were colored green.

Temp Bin (°C)	All Sites	*Atyoida bisulcata*	*Awaous guamensis*	*Eleotris sandwicensis*	*Kuhlia xenura*	*Lentipes concolor*	*Macrobrachium lar*	*Neritina granosa*	no species observed	*Poecilia reticulata*	*Procambarus clarkii*	*Sicyopterus stimpsoni*	*Stenogobius hawaiiensis*	*Xiphophorus helleri*
16	1	0.71	0.12	0.00	0.00	0.55	0.46	0.53	0.46	0.00	0.19	0.38	0.00	0.07
17	1	0.61	0.17	0.00	0.00	0.48	0.38	0.44	0.63	0.00	0.45	0.29	0.00	0.32
18	1	0.40	0.27	0.07	0.17	0.49	0.45	0.44	0.71	0.02	0.79	0.36	0.03	0.58
19	1	0.31	0.25	0.11	0.26	0.22	0.27	0.14	0.93	0.18	0.68	0.18	0.03	0.87
20	1	0.24	0.24	0.15	0.43	0.24	0.46	0.17	0.87	0.29	0.42	0.21	0.04	0.80
21	1	0.15	0.25	0.12	0.42	0.29	0.62	0.26	0.83	0.35	0.14	0.27	0.09	0.80
22	1	0.13	0.31	0.14	0.61	0.37	0.86	0.34	0.71	0.48	0.15	0.30	0.19	0.65
23	1	0.07	0.35	0.17	0.68	0.32	0.88	0.36	0.62	0.70	0.12	0.38	0.39	0.59
24	1	0.03	0.44	0.23	0.70	0.38	0.91	0.36	0.55	0.79	0.06	0.47	0.51	0.42
25	1	0.01	0.56	0.20	0.55	0.44	0.85	0.39	0.52	0.62	0.04	0.72	0.54	0.26
26	1	0.00	0.77	0.45	0.64	0.50	0.79	0.35	0.43	0.34	0.00	0.83	0.67	0.12
26+	1	0.00	0.86	0.54	0.68	0.52	0.75	0.37	0.39	0.25	0.00	0.90	0.71	0.04

Appendix 4: HDSS data collection

Introduction:

This report documents the results of the High Definition Stream Surveys (HDSS) data collection on Manoa Stream, Oahu. The Department of Land and Natural Resources, Engineering Division requested Parham & Associates Environmental Consulting, LLC to collect data on Manoa Stream. The request for these data was to better understand the environmental impact of flood control structures proposed within Manoa Stream. Specifically, the Engineering Division is planning to construct the Woodlawn Chute Flood Control Structure. The Woodlawn Chute project focuses on channel improvements under and downstream of the bridge on Woodlawn Drive. In general, the channel improvements can be described as: (1) widening and stabilizing the stream banks and (2) grading the stream channel to allow water to flow more swiftly through this channel segment, thus lowering the overall flood risk at the site. In addition to the Woodlawn Chute structure, the U.S. Army Corps of Engineers are planned to add nine additional flood control structures within the Ala Wai Watershed (Manoa Stream) and this data will be used to support this effort as well.

This HDSS data collection effort is part of a larger project. The data collected in this project is to be incorporated into a Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model to assess three different conditions: the current conditions within the site, the conditions with the flood control project, and the mitigation burden as a result of the project. This larger project includes fish surveys collected by the Department of Land and Natural Resources, Division of Aquatic Resources (DAR) and the overall model integration by researchers at Bishop Museum. This report will focus on the results of the HDSS effort within Manoa Stream and not on the larger results of the HSHEP model or overall mitigation effort.

In general, the HDSS approach is a multi-attribute, high resolution sampling technique that collects data of both streambanks and the stream channel bottom at approximately 1 m intervals. This approach is an improvement over traditional transect methods because the data collection is continuous over the survey area as opposed to being limited to small survey areas. For this project we collected data throughout Manoa Stream, including all of the Palolo and Makiki tributaries, to better understand conditions within and outside all of the project footprints. The HDSS technique integrates GPS, video, depth, and water quality sensors in a single pass. These results can be easily mapped to better understand conditions at the survey site. The following is a description of the HDSS methodology.

Methods:

Field Data Collection:

During the HDSS data collection process, two primary methods were used. A backpack-mounted HDSS system accounted for the majority of the data collected. A bodyboard-mounted HDSS system was used in deeper sections of the stream. The two systems shared many features. All video collected was geo-referenced to a GPS data stream so that an X,Y locational coordinate was associated with each second of video collected. Water quality was collected using a YSI EXO1 sonde will at point locations throughout the stream. When using the backpack HDSS system, depth was classified from the video collected, while when using the bodyboard-mounted HDSS system, depth was collected from a hull-mounted transducer.

The backpack-mounted HDSS system featured four different high definition video cameras with image stabilization (Figure 1). One camera was faced forward, one camera was faced downward, and a single camera was faced at the right and left banks. When using the backpack-mounted HDSS system, the surveyor moved in an upstream direction attempting to follow the thalweg of the stream. The bodyboard-mounted HDSS system included two additional cameras (Figure 2). These cameras were faced at a 45° angle downward towards the stream bottom. When using the bodyboard-mounted HDSS system, the bodyboard was drifted downstream under control of a long extension pole.

The GPS signal was collected using a Garmin 64C handheld GPS and a Garmin 19X GPS receiver. In both of these cases, the GPS NMEA data string was recorded at 1 Hz (approximately 1 sec interval). All data including the video and GPS track logs were saved to multiple external hard drives at the end of each day in the field. The track log for the GPS signal was exported in GPX format and the data was stored in a Microsoft Access database. The video was further post-processed in Adobe Premiere software to create a single view that encompassed all four video streams.

Figure 54: The author wearing the backpack-mounted HDSS system.

Figure 55: The bodyboard-mounted HDSS system.

<u>Video Classification:</u>

The HDSS video was classified by applying a standard classification system for each variable under consideration. The individual classes within each category are described below, but in general the process for each classification pass was similar. Prior to classification, the technician was trained on a subset of the videos under supervision of the principal investigator. Each video was watched by a technician and the category under consideration was scored. The HDSS Video Coder software version 2 (Parham 2014) was used to facilitate the classification process (Figure X). This software allows the human classifier to select the appropriate class and have it tied to the second it occurs in the video. In addition to the appropriate category classes, several additional classes were included in most categories. Unknown class was reserved for areas where the appropriate category was not visible to or otherwise noted by the surveyors. Other 1 and Other 2 classes were reserved for classes not accounted for in the above classification or for areas where the classifier had trouble determining class membership. These areas were then revisited with the field surveyors to decide on the appropriate class.

Once the classification was completed for the entire group of videos, an overall spreadsheet containing the video file name, the second at which the category occurred, the class name, and the class code was created. Given the unique combination of video name and second, we were able to link the classified spreadsheet with the GPS coordinates contained within the database.

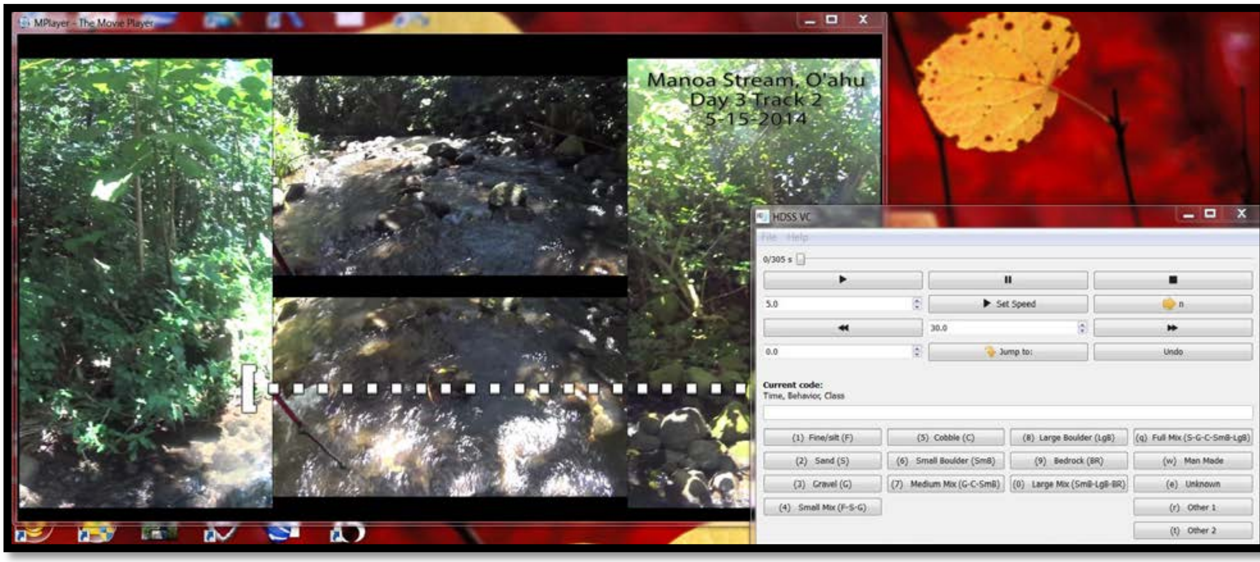

Figure 56: A computer screen image of the HDSS Video Coder Version 2 software and associated HDSS video of Manoa stream. In actual application, multiple computer monitors are used so that the HDSS video is displayed at high resolution on one monitor and the HDSS Video Coder software is displayed on a different monitor.

<u>Classification Categories:</u>

At each point, data for the following variables were estimated from the HDSS video:

- Habitat Type
- Depth
- Substrate
- Embeddedness
- Channel Condition
- Channel Width
- Percent Wetted Width
- Right and Left Streambank Height
- Right and Left Streambank Angle

- Right and Left Streambank Surface Protection
- Right and Left Riparian Zone Condition

The following describe each classification category.

Habitat Type

1. Pool
2. Run
3. Riffle
4. Cascade
5. Falls
6. Pocket Water
7. Sheet Flow
8. Unknown

Habitat type is one of the primary measures in describing instream habitat. Habitat types represent the classic riffle-run-pool combinations found in most streams. In general, the habitat types classified from the HDSS videos are compatible with those habitat types used by DAR in their habitat and fish surveys. Two additional classes were added. Pocket water represents a mix of riffle, run, and small pool habitat commonly found in the mid to upper reaches of the stream. Sheet flow is characteristic of the habitat found in man-made channelized stream sections. Transitions from one habitat type to the other were visually determined from experience by the primary investigator.

The following are examples of some of the more common habitat types found in the stream:

Figure 57: Habitat Types of Pool and Falls are shown in the image.

Figure 58: Run Habitat Type. The water is moving, but not broken on the surface.

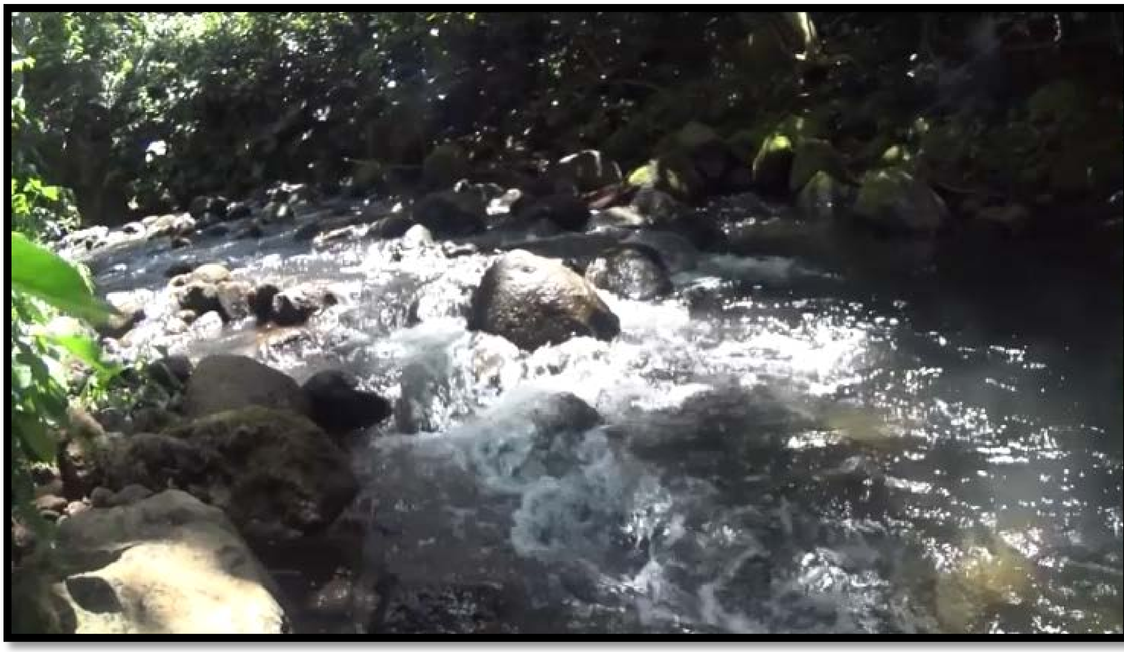

Figure 59: Riffle Habitat Type. Swiftly flowing water with broken surface.

Figure 60: Cascade Habitat Type. Note the high velocity, highly mixed flow in center of the image.

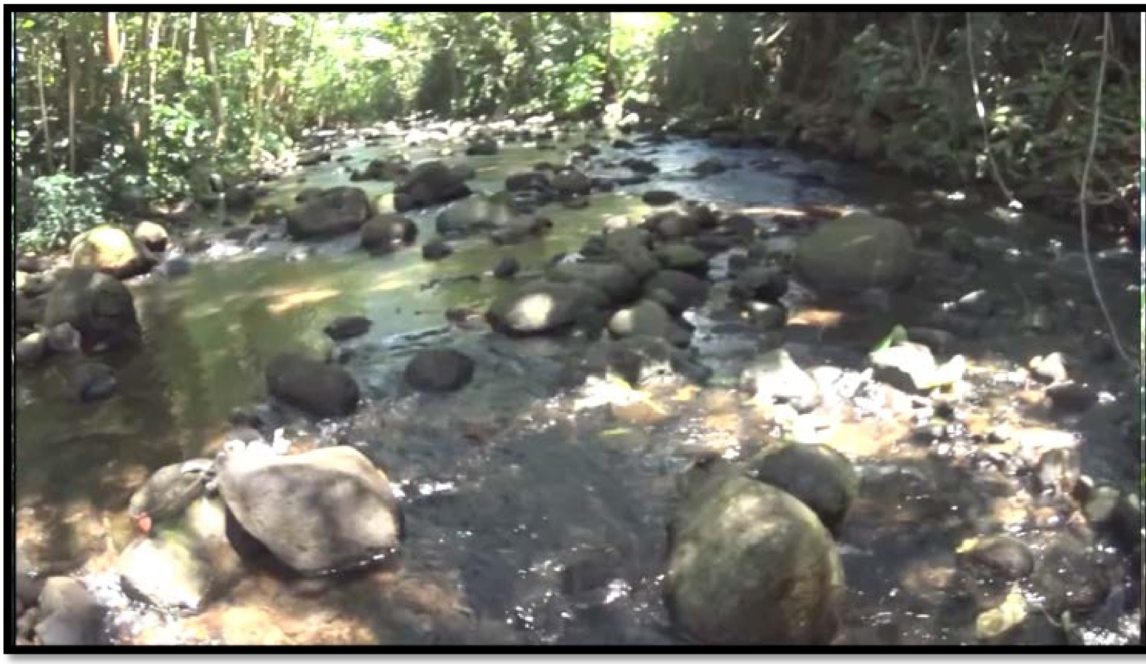

Figure 61: Pocket Water Habitat Type. Note the mixture of riffles, runs and small pools intermixed across the channel.

Figure 62: Sheet Flow Habitat Type is swift, shallow and uniform and is characteristic of fully channelized stream sections.

Depth:

1. Dry
2. 1-3 inches
3. 3-6 inches
4. 6-12 inches
5. 12-24 inches (1-2 ft deep)
6. 24-36 inches (2-3 ft deep)
7. 36+ inches (>3ft deep)
8. Unknown

The Depth category was intended to capture the thalweg depth for the main flow of the stream channel. The thalweg can be considered the center of the main flow and usually the deepest depth across the stream channel. The wading poles (as seen in the down-looking video) are set at 1 ft at the first black joint and 2 ft at the second joint for reference. In deeper sections, verbal documentation of depths by the surveyors may have been noted for reference.

The following are some example of depth classes observed in the surveys:

Figure 63: Depth class of 1 to 3 inches deep. This class was common in the fully channelized stream sections.

Figure 64: Depth class of 3 to 6 inches.

Figure 65: Depth class of 6 to 12 inches. Note the first clasp of the wading staff is above the water surface.

Figure 66: Depth class of 1 to 2 feet deep. Note second black clasp on wading staff denoting 2 ft deep is just above the water surface.

Figure 67: Depth class of 2 to 3 ft deep. Note the second clasp on the wading staff is fully underwater.

Figure 68: Depth class of greater than 3 ft deep. Note the right wading staff fully underwater.

Substrate:

1. Detritus (D): Dead particulate organic matter. Typically woody or leafy plant debris.
2. Fine/silt (F): All sediments finer than sand. Covers the Mud and Silt categories in the Wentworth Particle Classification Scale. Visually it is difficult to see individual grains of the sediment and if disturbed it easily clouds the water.
3. Sand (S): Observable small grains of sand ranging up to 2 mm in diameter. The covers all of the Sand category in the Wentworth Particle Classification Scale.
4. Gravel (G): From 2 mm to 64 mm in diameter. Visually this can be observed as small pebbles to rocks a little larger than a golf ball.
5. Small Mix (F-S-G)
6. Cobble (C): From 64 mm to 256 mm in diameter. Visually these can be observed as rocks from little larger than a golf ball to a volley ball size.
7. Small Boulder (SmB): From 256 to 610 mm or large rocks from 1 to 2 ft in diameter.
8. Medium Mix (G-C-SmB)
9. Large Boulder (LgB): Boulder greater than 610 mm (approximately 2 ft) in diameter
10. Bedrock (BR): Large areas of unbroken rock. Bedrock is typically smooth with some small cracks.
11. Large Mix (SmB-LgB-BR)
12. Full Mix (S-G-C-SmB-LgB)
13. Man-made: Any man-made substrate. Typically concrete.
14. Unknown

The classification is primarily based on the center (down-looking) video track where possible. The side-looking video was used for substrate classification when surveyor was not following the thalweg of the channel. Basing the substrate classification on the primary substrate in the channel thalweg is intended to achieve two things: (1) substrate type will vary with the thalweg depth criteria and thus will be more consistent among stream segments, and (2) may allow us to classify left and right channel substrate if necessary. For this habitat classification project, only the center (thalweg) channel substrate was scored.

Substrate classification is based on the substrate classification commonly applied by DAR in stream habitat surveys and can be considered a modification of the Wentworth particle scale (Higashi and Nishimoto 2007). The standard classes used in DAR surveys were modified to include several substrate mix classes as the visual assessment averages substrate type across several meters of the channel bottom. Man-made bottom type was generally concrete and found in channelized sections, but could include any non-natural bottom type.

The rules for determining specific substrate classes were as follows: if approximately 75% or more of the bottom is in a single class (i.e. gravel or cobble) then place it in the single substrate class. If it is mixed, pick the majority as small, medium, or large mix. Only use the full mix if the site contains a mix of everything small to large. In general, the mixes will be considered 33%, 33%, 33% of each substrate class. If it is 50/50% in two classes use the appropriate mix class as opposed to one or the other class. If you have a 50/50 mix of gravel and large boulder, go with the larger substrate class.

The following are examples of some of the more common substrate classes:

Figure 69: Small Mix substrate class. This is a mix of fine, sand, and gravel substrate classes.

Figure 70: Medium Mix substrate class. This is a mix of gravel, cobble and small boulder substrates classes.

Figure 71: Cobble substrate class. A few small boulders and some gravel were present, but the majority of the substrate is in the cobble class.

Figure 72: Large Boulder substrate class.

Figure 73: Full Mix substrate class. A wide range of substrate classes are visible from gravel to large boulder.

Figure 74: Bedrock substrate class

Figure 75: Man-made substrate class.

Embeddedness:

1. Optimal (0-25%)
2. Suboptimal (25-50%)
3. Marginal (50-75%)
4. Poor (75-100%)

The Embeddedness category refers to the extent at which rocks gravel cobble are covered or sunken in fine or sand substrates. We followed the EPA classification for high gradient streams with embeddedness ranging from optimal to poor depending on the extent that the large substrate is surrounded by fine substrate. Embeddedness is rated as the average of the most common condition and not reflective of a single boulder or cobble within the video frame. As with substrate, the embeddedness classification focused on the down-looking video where possible associated with the thalweg of the stream.

The following are examples of some of the more common embeddedness classes:

Figure 76: Optimal Embeddedness class. While some of the larger boulders are surrounded by smaller gravel or cobble, there is almost no fine or sand substrate surrounding the gravel and small cobbles.

Figure 77: Sub-optimal Embeddedness class. The larger cobbles are surrounded between 25% and 50% by fine or sand substrates.

Figure 78: Marginal Embeddness class. Note how the boulder and larger cobble are surrounded between 50% and 75% by fine or sand substrate.

Figure 79: Poor Embeddedness class. Most boulders are surrounded by greater than 75% by fine substrate.

Channel Condition:

1. Natural Channel
2. Natural Bottom – Walls far back
3. Natural Bottom – Left wall close
4. Natural Bottom – Right wall close
5. Natural Bottom – Both walls close
6. Fully channelized – low flow channel
7. Fully channelized – flat bottom
8. Unknown

The channel condition category is intended to capture the extent of channel modification at an individual location. In general, this category differentiates a natural stream channel from a channel with hardened walls from a fully channelized segment. The location of a man-made wall on either right or left bank and its proximity to the stream channel (close or far) was documented to aid in understanding available habitat and stream function within an area. The difference between close or far wall positions is if the wall is closer or further than 10 feet of the active channel. A low flow channel in a fully channelized segment was defined as an area of confined flow that constrains the majority of the low flow.

The following are examples of some of the more common channel condition classes:

Figure 80: Natural Channel class.

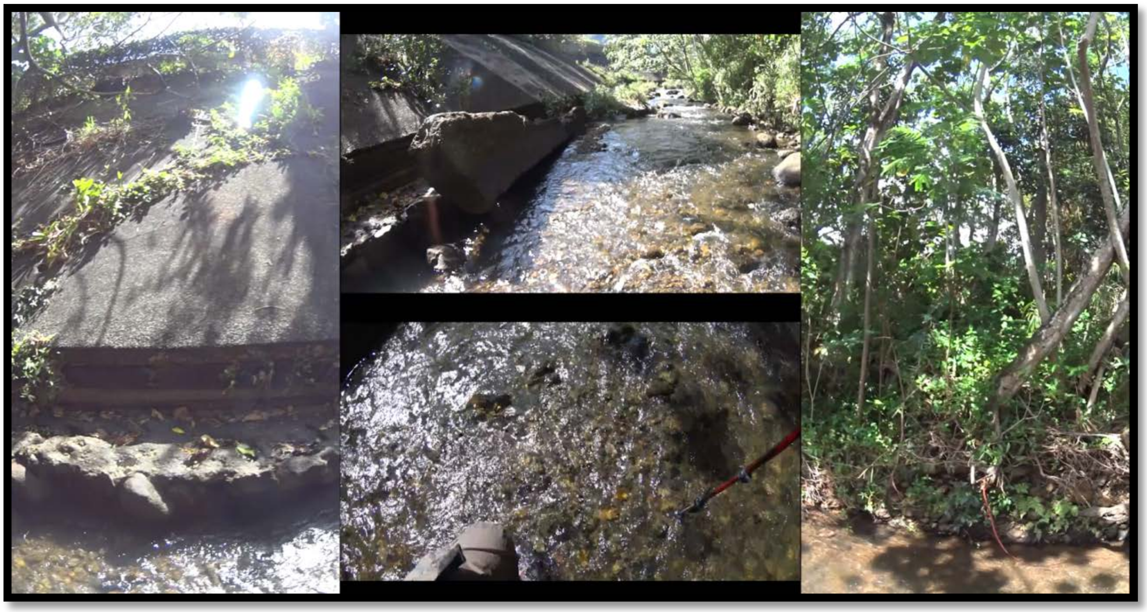

Figure 81: Natural Bottom: Left Wall Close class.

Figure 82: Natural Bottom - Both Walls Close class.

Figure 83: Fully Channelized - Flat Bottom

Channel Width:

1. Less than 10 ft. wide
2. Between 10 and 20 ft. wide
3. Between 20 and 30 ft. wide
4. Between 30 and 40 ft. wide
5. Greater than 40 ft. wide

The channel width metric categorically describes the stream’s active channel. This category is intended to help determine the potential habitat area of a stream segment. The longitudinal HDSS approach can determine channel length effectively. The combination of length and width provides a measure of total habitat area within the active channel. When channel width is used in combination with percent wetted width, a measure of wetted habitat area can be determined.

The following examples are some of the channel width classes:

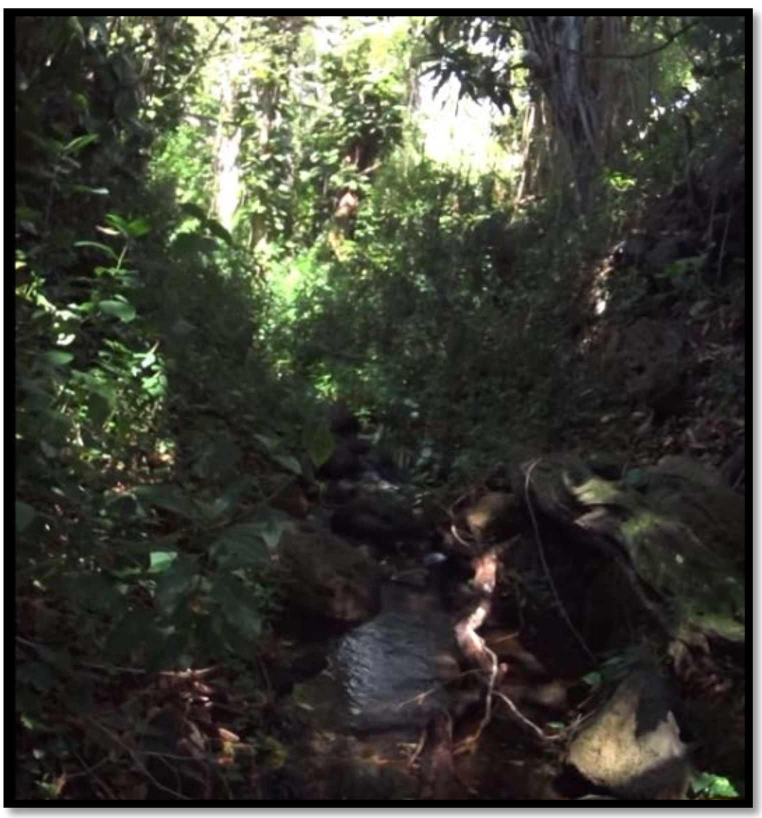

Figure 84: Channel width less than 10 ft wide.

Figure 85: Channel width between 10 and 20 ft wide.

Figure 86: Channel width between 20 to 30 ft wide.

Figure 87: Channel width between 30 and 40 ft wide.

Figure 88: Channel width greater than 40 ft wide.

Percent Wetted Width:

1. Dry
2. 1 -10%
3. 10-20%
4. 20-40%
5. 40-60%
6. 60-80%
7. 80-100%
8. Unknown

The category Percent Wetted Width is a descriptor of the extent at which the active channel is filled with water during the survey. Longitudinal changes in Percent Wetted Width can reflect changes in the base flow in the stream due to stream diversion, a losing or gaining reach, differences in channel morphology, or sections of unstable streams (i.e., incising or aggrading streams). There are more classes in the lower range of this category due to the critical nature of the amount of water found in the stream at very low flows.

The following are examples of some classes within the Percent Wetted Width category:

Figure 89: Percent Wetted Width class of 20 to 40%.

Figure 90: Percent Wetted Width class of 40 to 60%. Note that the active channel width includes the exposed rocks to the left of the image.

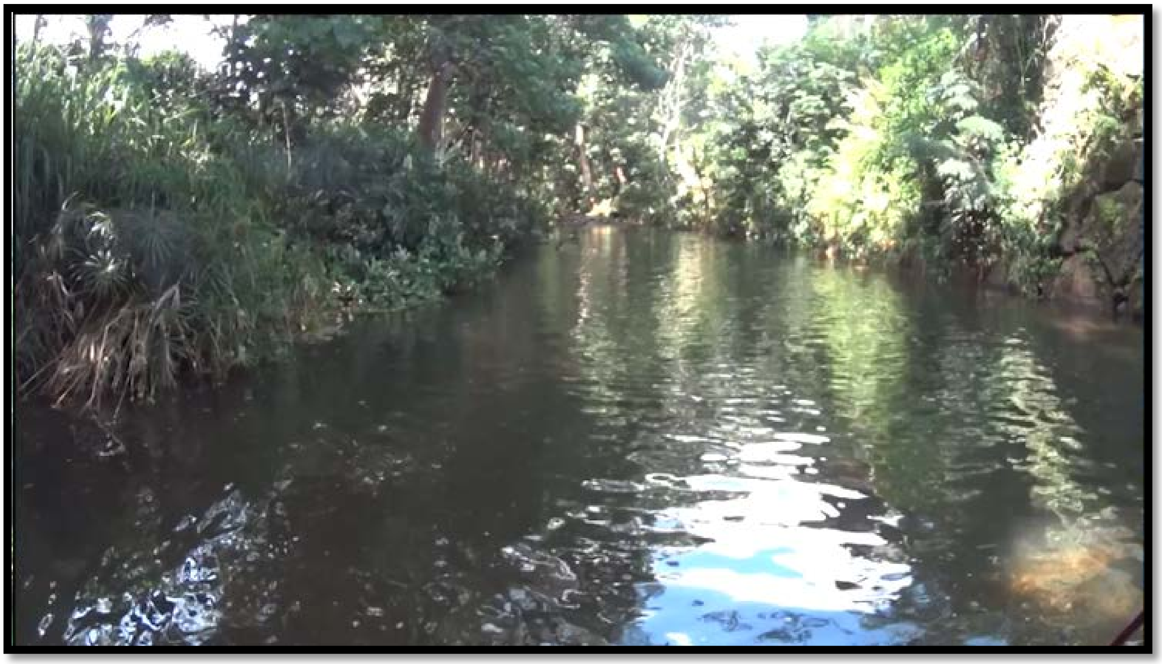

Figure 91: Percent Wetted Width class 80 to 100%.

Right and Left Streambank Height:

1. 0 to 1 ft
2. 1 to 3 ft
3. 3 to 6 ft
4. 6 to 9 ft
5. 9 to 12 ft
6. 12 to 18 ft
7. Greater than 18 ft
8. Unknown

Streambank height is relatively self-explanatory as it is the height of either the left or right streambank. The confusion comes and in determining where the streambank ends and the floodplain begins. This is further compounded in Manoa Stream as much of the stream is channelized or has setback flood control walls. For Manoa Stream, we define streambank height as the height of the wall if the walls were close to the active channel. At locations where there was no flood wall or the flood wall was far back from the active channel, streambank height was considered the height to the first bench.

Documenting streambank height is important in understanding channel volume, flow characteristics, and the stability of the streambank. Streambank height and bank angle may also indicate areas of channel incision or aggradation.

The following are examples of some classes within the Streambank Height category:

Figure 92: Streambank Height class for 3 - 6 ft.

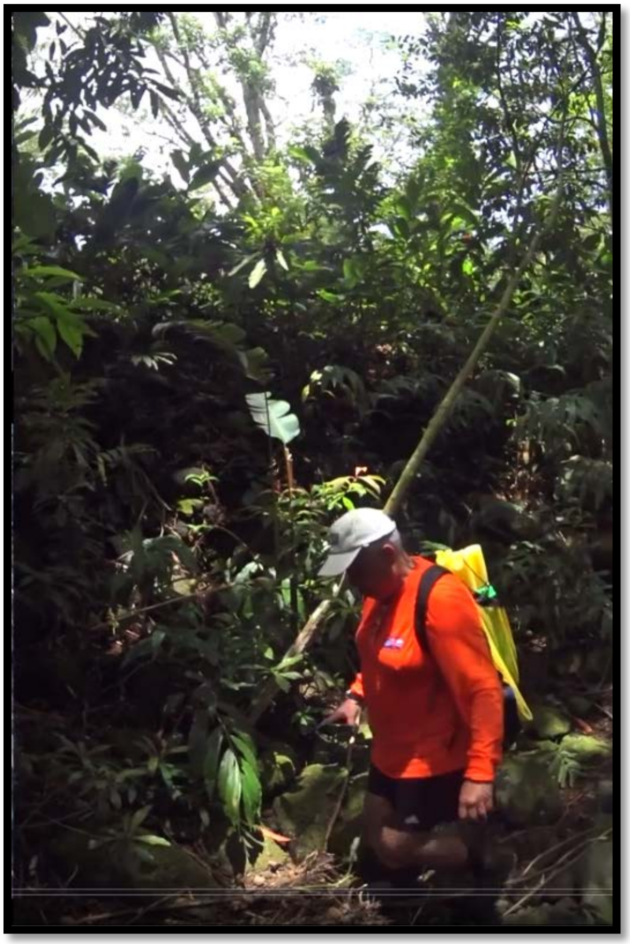

Figure 93: Streambank Height class for 6 - 9 ft.

Figure 94: Streambank Height class for greater than 18 ft. This image highlights the scoring when a flood wall is close to the streambank. Where the wall is close, the bank height equals the height of the wall. If the wall had been set further back, then height would equal the first bench in the front.

Right and Left Streambank Angle:

1. Low (0 - 60°)
2. Medium (61 - 80°)
3. High (81 - 90°)
4. Extreme (>90°)
5. Unknown

Streambank angle documents how steep or shallow the bank is where it enters the water. Streambank angle must be considered in combination with streambank height as the overall angle should be determined from the water level to the top of the streambank. In locations with near vertical or overhung bank angles there is greater potential for bank failure or streambank erosion.

The following are examples of some classes within the Streambank Angle category:

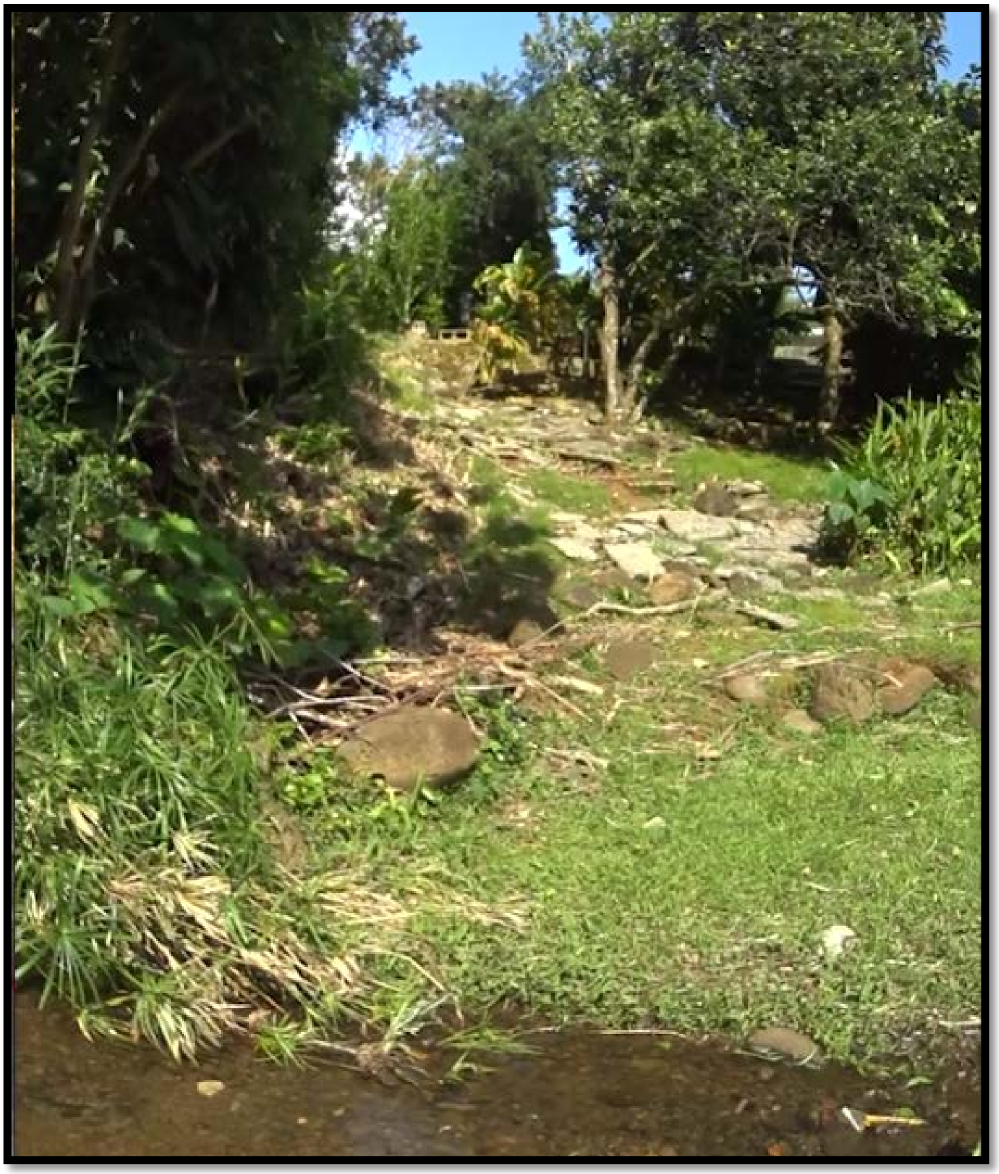

Figure 95: Low streambank angle (<60°).

Figure 96: High streambank angle (near 90°).

Figure 97: Extreme streambank angle (>90°, or undercut).

Right and Left Streambank Surface Protection:

1. Optimal (greater than 56% protected)
2. Sub-optimal (30 to 55% protected)
3. Marginal (15 to 29% protected)
4. Poor (less than 15% protected)
5. Unknown

Surface protection class is related to the percentage of the stream bank covered and protected from erosion by plant roots, downed logs and branches, and rocks. This metric is scored independently for both the left and right streambank. These classes follow the classes described by Connell (2012) as a modification of those of Rosgen (2001). Surface protection can be an important variable in and of itself, yet is more commonly combined with other variables to aid in determining overall streambank erosion potential.

The following are examples of streambank surface protection classes:

Figure 98: Optimal streambank surface protection. The banks are fully covered by vegetation minimizing possible surface erosion.

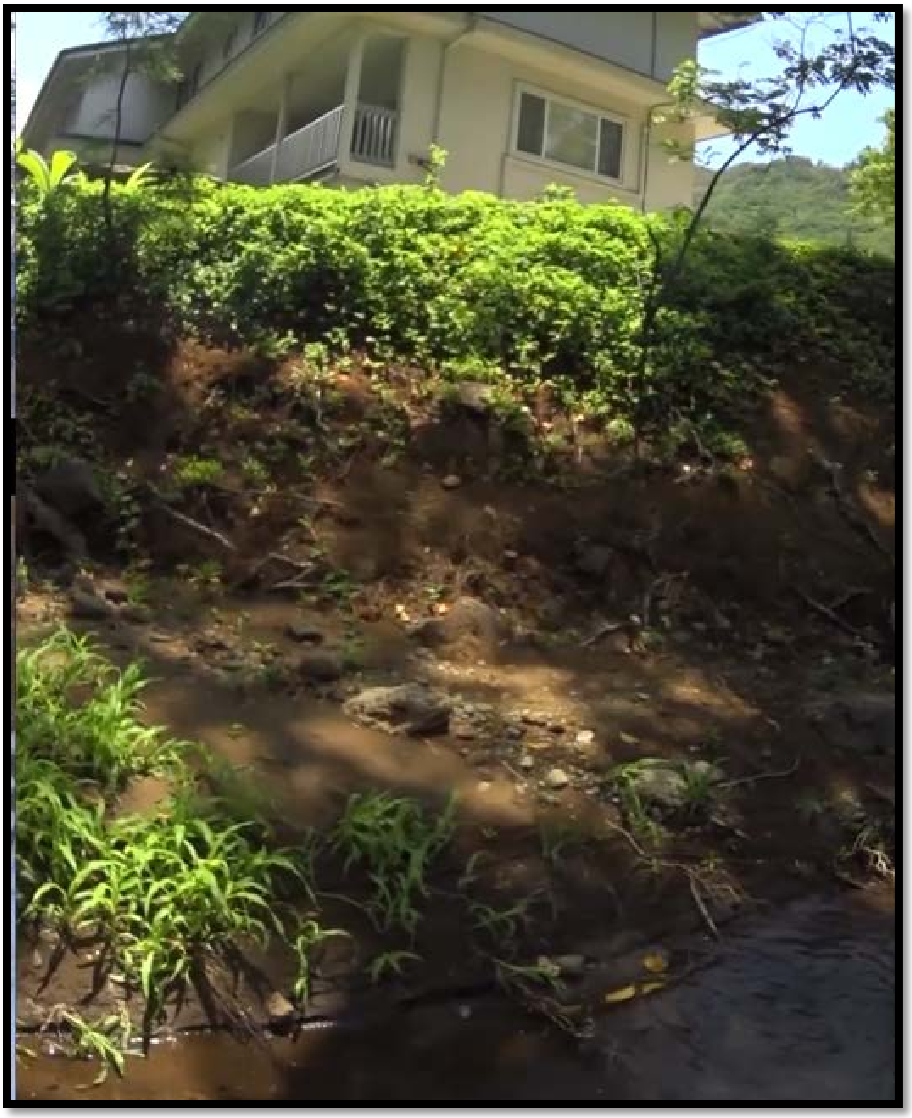

Figure 99: Poor and Marginal streambank surface protection. Here the bank is transitioning from an area of poor surface protection (right) to marginal surface protection (left). Note the high potential for surface erosion at this location.

Right and Left Riparian Zone Condition:

1. Optimal (presence of large trees or a wide variety of plant diameters)
2. Sub-optimal (mostly small trees or shrubs)
3. Marginal (mostly tall grasses)
4. Poor (lawn grass, pavement, or bare soil)
5. Unknown

For the purposes of this study, riparian zone condition refers to the extent at which the streambank or floodplain is vegetated by various sized trees. At one extreme there may be no riparian zone vegetation and at the other large trees can dominate the area near the banks of the stream. Where large trees exist, the stream is more likely to be shaded and thus have lower average stream temperatures. The root structures on the trees also stabilize the bank and prevent lateral in-cutting during flooding events. Much of Manoa Stream lacks a true riparian area thus this measure was adjusted to consider any vegetation within the stream channel corridor.

The following are a few examples of the Riparian Zone Condition classes:

Figure 100: Poor Riparian Zone Condition. No trees, shrubs or tall grasses to provide shading.

Figure 101: Marginal Riparian Zone Condition. Here large grasses are the primary cover and the trees are relatively far off the stream channel.

Figure 102: Optimal Riparian Zone Condition. There is a dense stand of moderate sized trees. If the trees were all small it would likely fall into the sub-optimal class.

Figure 103: Optimal Riparian Zone Condition. This location has very large tree that provide bank stability as well as stream shading.

Streambank Erosion Potential:

Streambank Erosion Potential is a derived metric that is formed from a combination of bank height, bank angle, and bank surface protection. Streambank erosion potential was modified from the calculation and scoring system described in Connell (2012). The modification involved the removal of the riparian zone condition score from the overall metric. This change was made to better represent the majority of the conditions observed in Manoa Stream. The streambanks of Manoa Stream are highly modified. In most places the stream channel is constrained by flood control walls and the riparian zone is highly urbanized. As a result the riparian metric represents the extent at which trees grow inside the flood walls and is used to represent the extent of stream shading not root depth as the riparian metric is traditionally used for. A further modification involved scoring where flood walls occurred near the stream. In this case, the concrete or grouted-rock walls had low erosion potential under any flow condition, therefore, where flood walls existed close to the stream channel, streambank erosion potential was low.

After determining the final streambank erosion potential score, the values were range standardized between 0 and 1. The range standardized value was inverted so that high bank erosion potential scores were near zero and low bank erosion potential scores were near one. This was done to allow this metric to be combined with other habitat modification metrics in an appropriate scale. Additionally, a combined metric for right and left bank scores was created by selecting the maximum value of the two scores. This single score represents the estimated likelihood of sediment entering into the adjacent instream habitat.

The Streambank Erosion Potential metric is calculated independently for each bank as follows:

$$\begin{aligned} &Streambank\ Erosion\ Potential\ (for\ each\ bank) \\ &\qquad = Bank\ Height\ score + Bank\ Angle\ Score + Surface\ Protection\ Score \end{aligned}$$

$$where: if\ [channel\ condition] indicates\ presence\ of\ flood\ wall\ close\ to\ channel,$$

$$then\ Streambank\ Erosion\ Potential\ is\ low$$

The following are a few examples of the component and overall Streambank Erosion Potential scores:

Figure 104: Low Potential for Bank Erosion. Bank Angle is just under vertical and the Bank Surface Protection is highly protected due to gabion baskets. There is no riparian diversity which means no root structure to hold together the rocks, but this has been functionally replaced by the braided wire fence.

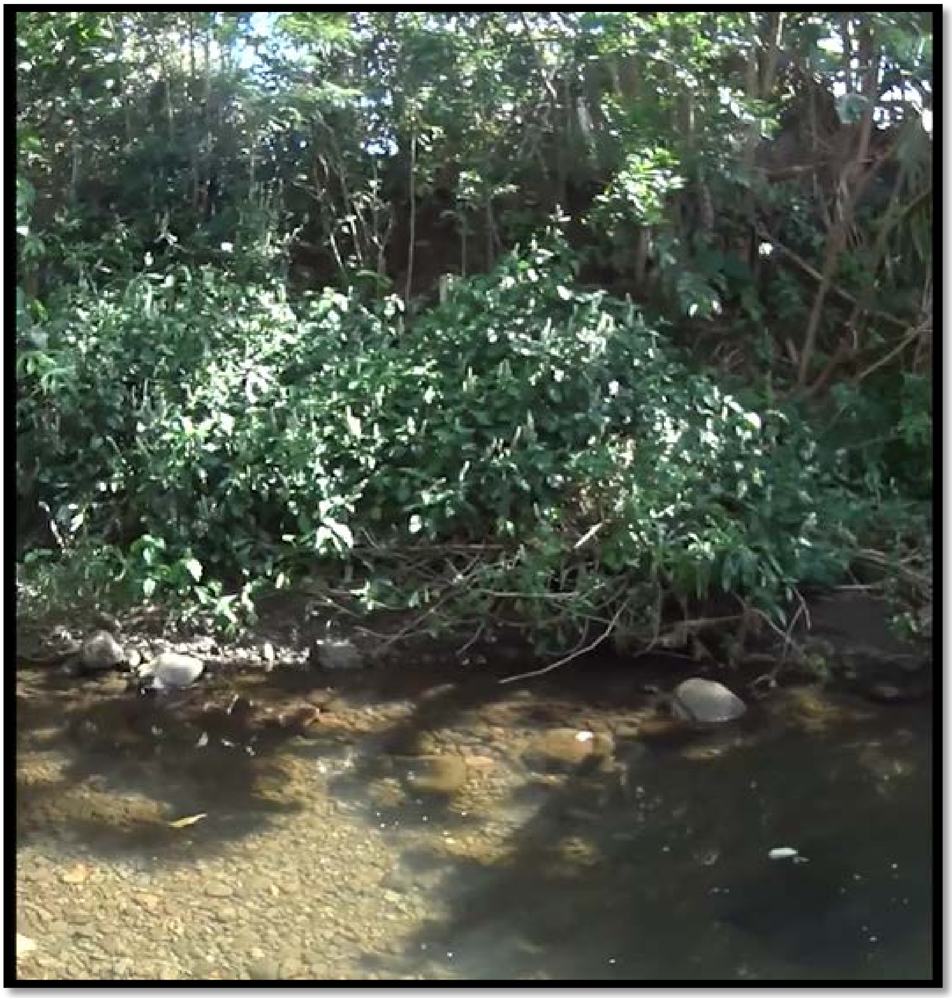

Figure 105: Moderate Potential for Bank Erosion. Bank angle is relatively steep (between 60-80°), Surface Protection is good, but there is some exposed bank. The Bank Height is rather tall (9 to 12 ft) and the Riparian Zone displays a lack of larger diameter vegetation.

Figure 106: High potential for Bank Erosion. The bank shows an almost undercut bank angle with marginal surface protection due to limited vegetation on the top part of bank and poor riparian diversity due to the complete lack of roots. Bank erosion is likely during high water events.

Fish Classification:

Native Fishes: O'opu nakea (*Awaous stamenius*), O'opu naniha (*Stenogobious hawaiiensis*), O'opu nopili (*Sicyotperus stimponi*), O'opu alamo'o (*Lentipes concolor*) O'opu akupa (*Eleotris sandvicensis*), Aholehole (*Kuhlia zenura*), Mullet (*Mugil cephalus)*

Native Crustaceans and Mollusks: Opae oeha'a (*Macrobrachium grandimanus*), Opae kala'ole (*Atyoida bisulcata*), Hihiwai *(Neritina granosa*), Hapawai (*Neritina vespertina*)

Introduced Fishes: Armored Catfish (*Hypostomus c.f. watawata)*, Bristlenose Catfish (*Ancistrus c.f. temmincki*), Bronze Corydoras (*Corydoras aeneus)*, Liberty Molly (*Poecilia sp. hybrid complex)*, Green Swordtail (*Xiphophorus hellerii)*, Guppy (*Poecilia reticulata)*, Mosquitofish (*Gambusia affinis*), Blackchin Tilapia (*Sarotherodon melanotheron)*, Convict Cichlid (*Amatitlania nigrofasciata)*, Smallmouth Bass (*Micropterus dolomieu)*, Carp (*Cyprinus carpio)*, Goldfish *(Carassius auratus)*

Introduced Crustaceans, Mollusks, and Amphibians: Tahitian prawn (*Macrobrachium lar*), Grass Shrimp (*Neocaridina denticulata sinensis*), Crayfish (*Procambarus clarkii*), Cane Toad (*Bufo marinus*)

Fish and other stream animal surveys were accomplished using two methods. The first method was visual surveys completed as the HDSS habitat surveys were underway. The visual surveys were further confirmed with net samples conducted by DAR biologists and technicians. While the visual surveys were widespread and covered all the habitat areas, these surveys likely missed some small or cryptic animals.

Figure 107: An example of a large Koi (Cyprinus carpio) captured during the net surveys.

Figure 108: Native mollusk, *Neritina vespertina*, on rock from in the lower reach of a stream.

The second and more extensive fish and aquatic animal survey involved the use of the High Definition Fish Survey (HDFS) approach. The HDFS approach utilized pole-mounted, high-definition, underwater video cameras to capture images of fish or other aquatic animals at a specific location. The underwater cameras were also geo-referenced so that specific time and place information was recorded for all video observations. By logging GPS data with underwater video, the HDFS results can easily be integrated with the HDSS habitat information gathered at the same location.

Figure 109: Underwater geo-referenced video camera used during the HDFS observations.

In general, the HDFS sample could be considered a point sample. The cameras are moved into position, slowly lowered to the bottom, and then remain in position for approximately 15 seconds to capture a sample of animals at that location. This process is repeated at sites distributed evenly throughout the available habitat. To document the animals observed in the videos, the HDSS video coder software with a list of potential animal species was used. During classification, a start code was inserted when the camera was in position. Next, all species were recorded, and then a stop code was recorded. This process allowed only high-quality underwater video samples to be used and to link the appropriate GPS data for that location. Habitat data associated with the fish samples was linked from the HDSS data collection.

The following are some examples of stream animals observed during the HDFS sample collection from various Hawaiian streams:

Figure 110: Native fish, *Awaous steminus,* in a stream pool.

Figure 111: Native fish, *Sicyopterus stimpsoni,* on boulder substrate.

Figure 112: Native species, *Kuhlia zenura*, in the lower reach of a stream.

Figure 113: Introduced swordtails, *Xiphophorus hellerii*, observed at high density.

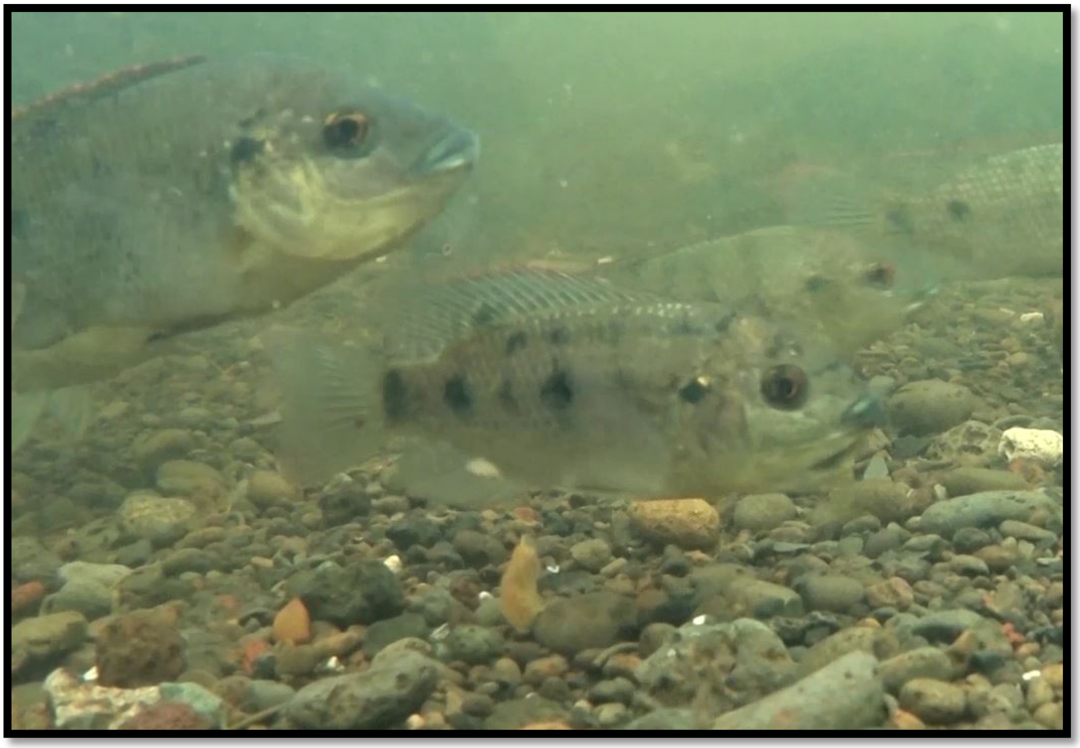

Figure 114: Introduced Blackchin tilapia, *Sarotherodon melanotheron*, over gravel substrate.

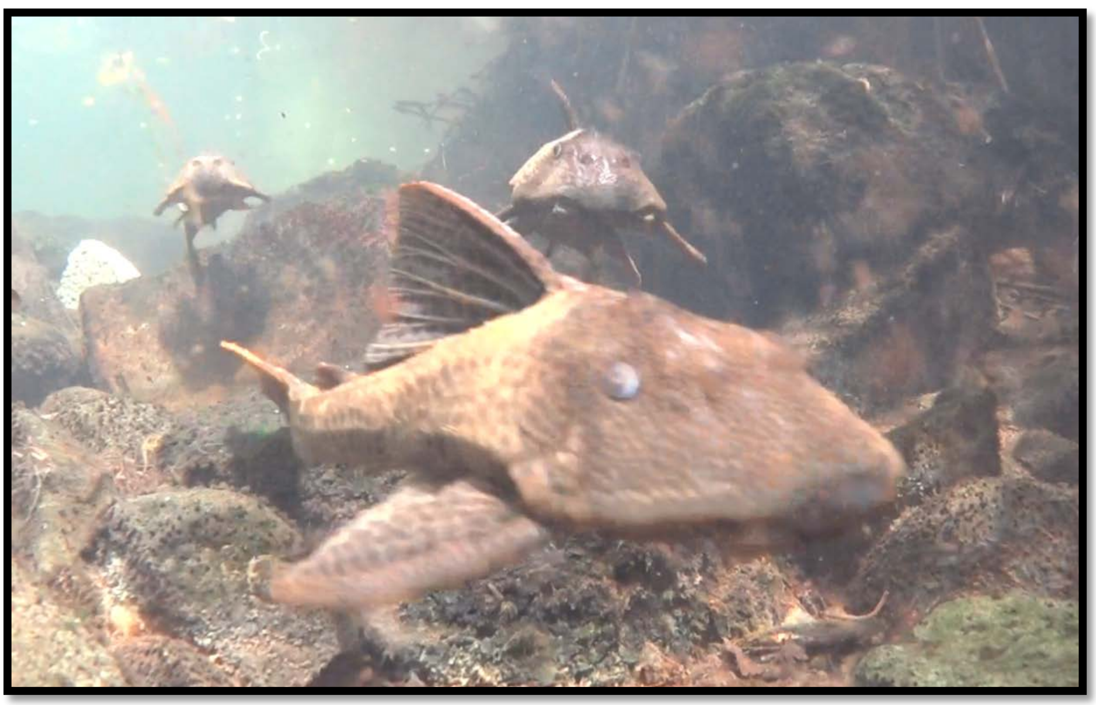

Figure 115: Introduced armored catfish, *Hypostomus c.f. watawata*, were found in large aggregations.

Attachment 2. Single-Use Approval of the Hawaiian Stream Habitat Evaluation Procedure for the Ala Wai Canal Flood Risk Management Project

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

REPLY TO
ATTENTION OF

CECW-P 28 May 2015

MEMORANDUM FOR Director, National Ecosystem Restoration Planning Center of Expertise (ECO-PCX)

SUBJECT: Single-Use Approval of the Hawaiian Stream Habitat Evaluation Procedure for the Ala Wai Canal Flood Risk Management Project, Hawaii

1. The HQUSACE Model Certification Panel has reviewed the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) in accordance with EC 1105-2-412 and has determined that the model and its accompanying documentation are sufficient to approve its use for the Ala Wai Canal flood risk managament study, Oahu, Hawaii. Adequate technical reviews have been accomplished and the Panel considered the assessments of the ECO-PCX and the Agency Technical Review in making this determination.

2. The HSHEP model was developed through collaboration between the Hawaii Division of Aquatic Resources and researchers at universities, state agencies, museums, and private entities. The model follows the Habitat Evaluation Procedure concepts and methodology to capture the major aspects of native stream animal ecology, geomorphology of Hawaiian streams, and common modifications to the environment. The intent of the model is to be useful in assessing the potential impacts of stream channel modification, flow alteration, land use change, climate change, stream restoration, and barrier modifications on native stream animal habitat quality and quantity. The HSHEP is designed to be used at site, stream segment, and stream and watershed scales depending on the scenario and level of detail required. Variables at the watershed scale include stream and watershed size, watershed wetness, watershed stewardship, the amount of estuary and shallow water marine habitats associated with the watershed, and the watershed land cover quality. Variables in the model describe instream habitat and animal distributions include factors such as elevation, distance from the ocean, and the presence of instream barriers. Finally, at the site level, more specific characteristics are included as suitability indices for six instream flow assessment (e.g., depth, velocity, and substrate) or habitat assessment (e.g., habitat type, depth, substrate, and temperature for habitat assessment) depending on the project objectives. Habitat suitability for eight species of native stream animals (i.e., five fish, two crustaceans, and one mollusk) was determined using presence/absence data as the basis for habitat utilization. Habitat utilization is the frequency of occurrence for an individual species in each habitat category. Suitability is developed by dividing the percent utilization for each habitat category with the percent available. The resulting suitability curve ranges from 0 (unsuitable) to 1.0 (highly suitable). By combining HSHEP results from multiple scales, the overall model provides an assessment of habitat suitability with respect to its location in a stream and is comparable.

3. The HSHEP model has been reviewed by the Hawaii Division of Aquatic Resources, the USFWS and private consultants utilizing the model for hydroelectric licensing applications. Additionally, the ECO-PCX managed a review of the HSHEP model. The review was conducted by an ecologist with expertise in tropical island flora and fauna, associated habitat requirements, and extensive ecological modeling expertise, Dr. Kyle McKay, ERDC Environmental Laboratory. Comments received pursuant to this review recommended actions to clarify and improve model documentation and improve the overall usability of the model. The model documentation and inherent user's guide was

updated to more explicitly describe the intended use and appropriate documentation for variables, use of scales, and addition of variables. Documentation was improved to further detail application methodology, assumptions and limitations of the model, and address statistical model development issues.

4. The HSHEP has sufficient technical quality, is computationally correct, meets usability criteria and is policy compliant.

APPLICABILITY: The HSHEP is approved for single use on the Ala Wai Canal flood risk management study, Oahu, Hawaii.

BRUCE D. CARLSON
Deputy Chief, Planning and Policy Division
Directorate of Civil Works

Attachment 3. Ala Wai Flood Control Project Impact to Native Stream Animal Habitat and Possible Habitat Mitigation Options

Ala Wai Flood Risk Management Project Impact to Native Stream Animal Habitat and Possible Habitat Mitigation Options

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Submitted to:

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Introduction:

The purpose of the Ala Wai Canal Project is to reduce the risk of flooding within the Ala Wai watershed. In general, the flood risk management project is focused on holding back or diverting peak flood flows to lessen the impact of a flooding event. The infrastructure needed to do this is expected to have an impact on aquatic habitat and native Hawaiian stream animals. This report is an accounting of the impacts of the flood risk management project on aquatic habitat and native Hawaiian stream animals, and potential mitigation plans to offset these impacts. The Hawaiian Stream Habitat Assessment Procedure (HSHEP) model was used to determine the impact and quantify mitigation scenarios. In addition to supporting the HSHEP model, long stretches of Manoa, Palolo and Makiki streams were surveyed to better understand instream conditions both at the impact sites and throughout the stream in general.

Data Collection and HSHEP Methodology:

The overall HSHEP approach and methodology was reviewed by the USACE and approved for use on the Ala Wai Flood Risk Management Project. The HSHEP for the Ala Wai Flood Risk Management Project followed the accepted approach and methods can be found in the document:

Parham, J.E. 2015. The Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model: Intent, Design, and Methods for Project Impact Assessment to Native Amphidromous Stream Animal Habitat. Submitted to Civil and Public Works Branch, U.S. Army Corps of Engineers, Honolulu District, HI. 178 pages.

Associated Data:

Also provided with this report are associated data tables and field videos. An Excel spreadsheet of the information associated with the stream segment results from the HSHEP model is named:

Parham, J.E. 2015. Ala Wai HSHEP Impact and Mitigation Worksheet: Spreadsheet of model outputs. Final Output.

There are also a number of video files from the High Definition Stream Surveys (HDSS) for the Ala Wai watershed streams (Table 1). The video files may be referred to as:

Parham J.E. and G.R. Higashi. 2015. High Definition Stream Surveys Video for the Ala Wai Watershed Streams: Video Name: *insert_name_here*.

The video names are as follows:

Table 1: HDSS Video Names for Ala Wai Watershed Streams.

HDSS_Video_Name
02_LowerManoa1
03_LowerManoa2
06_MaonaF2UH_final
07_UHupstreamT11_final
08_UHupstreamT12_final
09_UHupstreamT2_final
11_Track23_combined_final
13_ManoaDVpark_Up1Final
14_Manoa_D3T1a
15_Manoa_D3T2a
16_Manoa_D3T3a
17_Manoa_D3T3ba
18_Manoa_D3T4a
20_Upper_Trib
51_lowerPalolo1
54_PaloloMid1
55_PaloloMid2
58_UpperPaloloHDSS
80_Makiki1

Not all of the data could be presented effectively in this report. There were approximately 23,000 lines of data generated for the sites in the HSHEP model. This report summarizes the results in a segment by segment approach. All data will be made available with this report.

Geographic Area of Concern:

The overall HSHEP Model included Manoa Stream and its tributary Palolo Stream as well as Makiki Stream and Hausten Ditch which also flow into the Ala Wai Canal (Figure 1). These streams are all within the Ala Wai Watershed. The Ala Wai Flood Risk Management Project impacts various locations within Ala Wai Watershed streams. The stream segments are broadly numbered with lower numbers closer to the stream mouth and higher numbers toward the headwaters. Manoa Stream is numbered from 1 to 120, Palolo Stream 200 to 225, Makiki Stream 300 to 306, Hausten Ditch from 500 to 502. Table 1 shows the Segment IDs, Stream Name, and Flood Risk Management Site (Table 2).

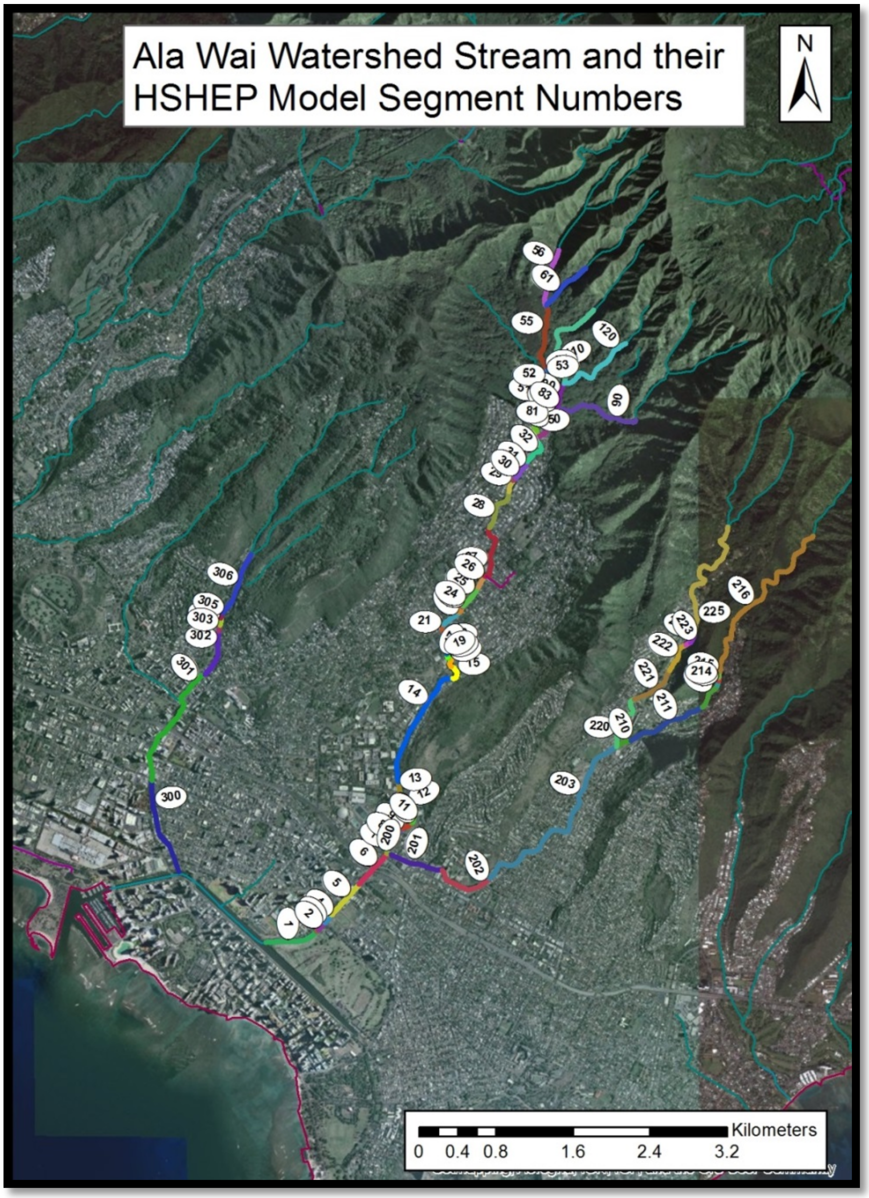

Figure 1: The Ala Wai Watershed Streams and the segment numbering used in the HSHEP model. Manoa Stream numbering goes from 1 at the stream mouth upstream to 120 in the upper reaches, Palolo Stream from 200 to 225, and Makiki Stream from 300 to 306.

Table 2: HSHEP Stream Segment ID, Name, and other information.

Segment ID	Stream Name	Tributary Name[1]	Key Site Description	Barriers: Falls Number (at start of segment)	Length[3] (m)	Width Class (ft)	Wetted Width (%)	Width (m)	Area (m^2)
1	Manoa	Manoa			520	80	90%	22	11,410
2	Manoa	Manoa	Ala Wai Golf Course Basin		22	80	90%	22	476
3	Manoa	Manoa			96	80	90%	22	2,115
4	Manoa	Manoa	Channel Maintenance Area		99	60	90%	16	1,638
5	Manoa	Manoa	Channel Maintenance Area		394	49	90%	13	5,304
6	Manoa	Manoa	Channel Maintenance Area		404	49	90%	13	5,407
7	Manoa	Manoa			108	36	90%	10	1,066
8	Manoa	Manoa			69	30	90%	8	569
9	Manoa	Manoa		Lower Falls	111	33	90%	9	1,004
10	Manoa	Manoa			96	33	90%	9	882
11	Manoa	Manoa	Kanewai Detention Basin		19	40	90%	11	212
12	Manoa	Manoa			320	35	90%	10	3,057
13	Manoa	Manoa			122	35	90%	10	1,171
14	Manoa	Manoa			1208	39	89%	11	12,714
15	Manoa	Manoa	State Woodlawn Chute Project		170	39	56%	7	1,132
16	Manoa	Manoa	State Woodlawn Chute Project		106	32	90%	9	942
17	Manoa	Manoa	State Woodlawn Chute Project		11	40	86%	10	116
18	Manoa	Manoa	State Woodlawn Chute Project		19	40	48%	6	111
19	Manoa	Manoa	State Woodlawn Chute Project		10	40	30%	4	36
20	Manoa	Manoa			228	33	30%	3	684
21	Manoa	Manoa	Channelized	Chan Barrier	74	50	30%	5	338
22	Manoa	Manoa	Channelized	Chan Barrier	199	50	30%	5	912
23	Manoa	Manoa	Channelized	Chan Barrier	55	50	30%	5	253
24	Manoa	Manoa	Manoa Instream Debris Catchment		13	44	68%	9	120
25	Manoa	Manoa			234	32	90%	9	2,078
26	Manoa	Manoa	Streambank Restoration Area		124	40	90%	11	1,362
27	Manoa	Manoa			564	35	89%	9	5,298

28	Manoa	Manoa		Barrier: Falls 6[4]	428	39	90%	11	4,567
29	Manoa	Manoa		Barrier: Falls 7	116	50	90%	14	1,597
30	Manoa	Manoa		Barrier: Falls 8	36	50	90%	14	498
31	Manoa	Manoa			197	50	90%	14	2,704
32	Manoa	Manoa			318	43	90%	12	3,784
50	Manoa	Waiahi			190	34	90%	9	1,759
51	Manoa	Waiahi		Barrier: Falls 11	366	30	75%	7	2,518
52	Manoa	Waiahi			73	30	75%	7	503
53	Manoa	Waiahi	Waiahi Detention Basin		37	30	75%	7	255
54	Manoa	Waiahi			60	30	75%	7	415
55	Manoa	Waiahi			617	20	90%	5	3,383
56	Manoa	Waiahi			567	15	90%	4	2,333
61	Manoa	Unnamed			531	15	90%	4	2,184
80	Manoa	Luaalaea			191	34	90%	9	1,768
81	Manoa	Luaalaea		Barrier: Falls 12	58	24	90%	7	387
82	Manoa	Luaalaea	Waiakeakua Detention Basin		63	27	90%	8	474
83	Manoa	Luaalaea			36	25	90%	7	247
90	Manoa	Waiakeakua			864	15	90%	4	3,557
100	Manoa	Luaalaea			257	20	90%	5	1,413
110	Manoa	Luaalaea			960	15	90%	4	3,949
120	Manoa	Naniuapo			815	15	90%	4	3,354
200	Palolo	Palolo			44	30	85%	8	344
201	Palolo	Palolo	Channelized	Chan Barrier	528	40	33%	4	2,086
202	Palolo	Palolo			570	30	86%	8	4,522
203	Palolo	Palolo	Channelized	Chan Barrier	2003	38	45%	5	10,451
210	Palolo	Waiomao	Channelized	Chan Barrier	154	35	45%	5	739
211	Palolo	Waiomao			789	35	45%	5	3,788
212	Palolo	Waiomao			275	22	83%	6	1,522
213	Palolo	Waiomao			40	25	90%	7	279
214	Palolo	Waiomao	Waiomao Detention Basin		34	20	90%	5	185
215	Palolo	Waiomao	Waiomao Detention Basin Excavation	Barrier: P_Falls 5	66	35	89%	9	620

216	Palolo	Waiomao			1852	15	90%	4	7,623
220	Palolo	Pukele	Channelized	Chan Barrier	566	40	50%	6	3,447
221	Palolo	Pukele			459	30	90%	8	3,777
222	Palolo	Pukele			308	30	90%	8	2,535
223	Palolo	Pukele	Pukele Detention Basin		54	30	90%	8	443
224	Palolo	Pukele			114	25	90%	7	785
225	Palolo	Pukele			1373	15	90%	4	5,648
300	Makiki	Makiki			940	40	90%	11	10,312
301	Makiki	Makiki	Channelized	Chan Barrier	1272	30	50%	5	5,814
302	Makiki	Makiki			454	18	84%	5	2,126
303	Makiki	Makiki			56	14	90%	4	220
304	Makiki	Makiki	Makiki Detention Basin		74	20	90%	5	404
305	Makiki	Makiki			57	16	90%	4	255
306	Makiki	Makiki			634	15	90%	4	2,607
500	Hausten	Hausten	Hausten Detention Intake		10	66	90%	18	181
501	Hausten	Hausten			150	66	90%	18	2,716
502	Hausten	Hausten	above Marco Polo Apts		560	44	90%	12	6,759

Description of Flood Risk Management Impact Areas:

<u>Site 1, Manoa Stream: Ala Wai Golf Course Basin Intake</u>

Segment ID: 2

Area Map:

Figure 2: HSHEP segment numbers associated with the Ala Wai Golf Course Detention Basin

Site Description: Manoa Stream is relatively wide at this location and the banks are covered with mangrove trees. The channel is constrained by man-made streambanks. The water is relatively slow moving and deep with fine substrates most common. This area is tidally influenced and what hard substrates do exist appear to be highly embedded with fine sediment.

The detention basin intake would be on the right hand shore looking upstream and would be a concrete structure that would fully harden a small section of the streambank. Instream habitat is unlikely to be greatly affected, as no plans for modification of the stream bottom are in the designs. The Expected Condition based on best professional judgment was a reduction in 20% of the habitat at the location due to the armoring of the streambank. The Worst-Case Condition reflected the maximum impact and was modeled at 100% loss of habitat as a result of the intake construction. The Worst-Case Condition likely far overstates the potential changes to instream habitat and its effects on native stream animals.

Figure 3: Looking upstream toward the Date Street Bridge. The golf course basin intake would be on the right.

Figure 4: Left bank looking upstream of lower Manoa Stream near the Date Street Bridge.

Figure 5: Right bank looking upstream of lower Manoa Stream near the Date Street Bridge. This is typical of the streambank condition at the basin intake site.

Site 2, Manoa Stream: Kanewai Field Multi-Purpose Detention Basin Intake

Segment ID: 11

Area Map:

Figure 6: HSHEP segment numbers associated with the Kanewai Field Detention Basin

Site Description: Manoa Stream is moderately wide and varies between riffles, runs, and pools in this area. The right bank looking upstream is already hardened with the majority of the riparian vegetation being found on the left-hand side. The site is a mix of substrates ranging from gravel to small boulders with cobble being the most common substrate type. The stream in this area has relatively decent instream habitat typical of mid-reaches in Hawaiian streams. There is some embeddedness from fine substrates due to upstream erosion.

Similar to the Ala Wai golf course basin intake, the detention basin intake at the Kanewai Field would be on the right hand shore looking upstream and would be a concrete structure that would fully harden a small section of the streambank. Instream habitat is unlikely to be greatly affected as no plans for modification of the stream bottom are in the designs. In the Expected Condition, our best professional judgment was a reduction in 20% of the habitat at the location due to the armoring of the streambank. The Worst-Case Condition was 100% loss of habitat as a result of the intake construction. The Worst-Case Condition likely far overstates the potential changes to instream habitat and its effects on native stream animals.

Figure 7: Below the Kanewai Field Intake Site looking upstream. This image shows instream conditions typical downstream of the impact site. Note the USGS gage site on the right bank.

Figure 8: Immediately below the Kanewai Field Intake Site. The large box culvert in upper center image is a reference to the site location.

Figure 9: Streambank and in-channel conditions at the Kanewai Field Intake site.

Figure 10: Looking upstream of the Kanewai Field Intake site.

Site 3, Manoa Stream: Manoa Instream Debris Catchment Site near Manoa Valley District Park

Segment ID: 24

Area Map:

Figure 11: HSHEP segment numbers associated with the Manoa In-Stream Debris Catchment Site.

Site Description: The site for the instream debris catchment is just upstream of a long channelized segment of Manoa Stream. This site is adjacent to the Manoa Valley District Park in the channel appears to have been straightened and widened in the past. Cobble and gravel are the primary substrates available with a small amount of fine sediment embedding of larger substrate types. The area is primarily a run habitat type mostly a foot or less in depth.

The impact at this location is expected to remove all instream habitat for native stream animals as the bottom will be entirely made of cement with the debris catchers rising up from it. Thus, the Expected Condition is in line with the Worst-Case Condition modeled as a total removal of the habitat.

Figure 12: Downstream of Debris Catchment site. Note that the stream is fully channelized here.

Figure 13: At the end of the channelized section immediately downstream of the Debris Catchment site.

Figure 14: Debris Catchment site. Manoa Valley District Park is on the left side of the image.

Figure 15: Upstream of the Debris Catchment Site. Instream habitat is similar from the end of the channelized segment to the bridge above.

Site 4, Manoa Stream: Woodlawn Ditch Detention Basin

Segment ID: no ID number (not perennial stream at Detention Basin site)

Area Map:

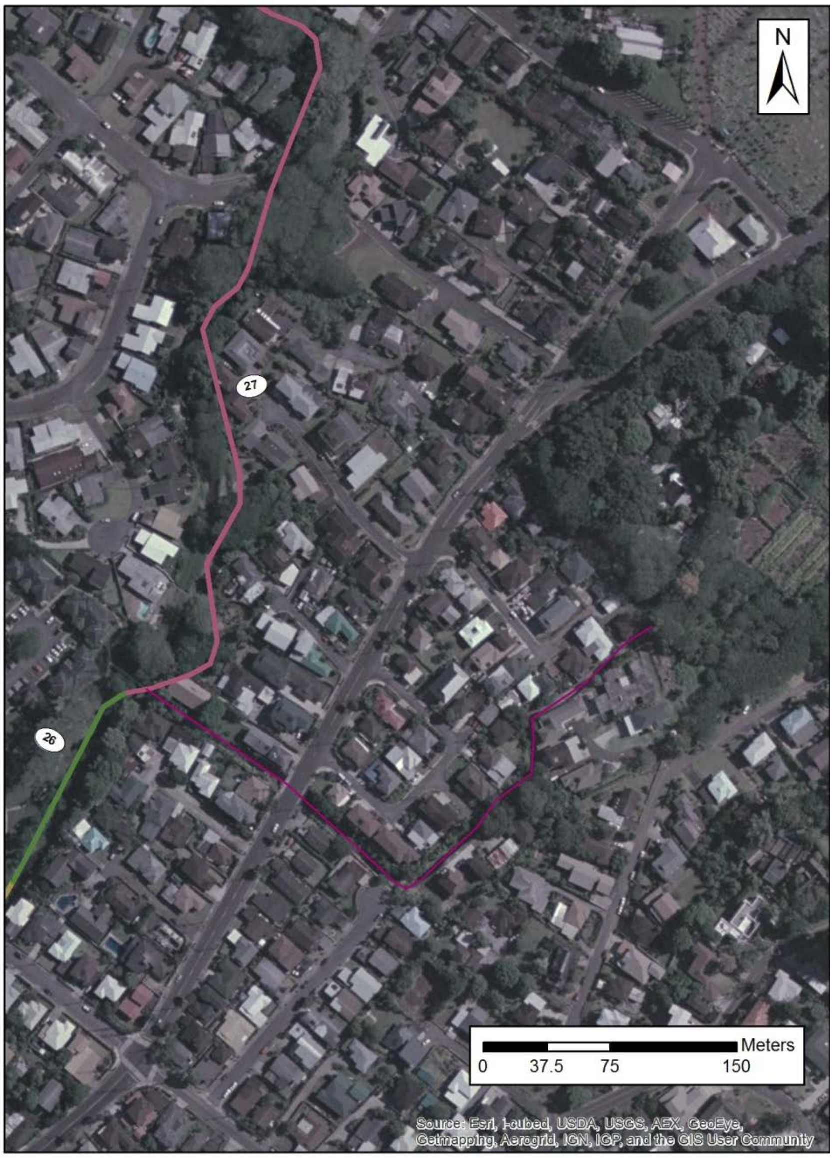

Figure 16: Map of the Woodlawn Ditch stream segments downstream of detention basin site.

Site Description: The Woodlawn Ditch was surveyed by state biologists and technicians. The ditch appears to have perennial flow in the lower end and becomes intermittent in the area of the planned detention basin. The stream was not surveyed directly in the impact area, but it was dry above it and was very small below it. Under best of conditions, the amount and quality of instream habitat for native amphidromous stream animals would be limited, but with its designation as an intermittent stream, we did not include it in the model as by definition it would not support the stream animals of concern.

Figure 17: Mouth of the Woodlawn Ditch entering Manoa Stream. Ditch is entering on the right side of stream.

Figure 18: Downstream view of Woodlawn Ditch from East Manoa Road Bridge. (G. Higashi, DAR photo)

Figure 19: View straight down from East Manoa Road Bridge into Woodlawn Ditch. (G. Higashi, DAR photo)

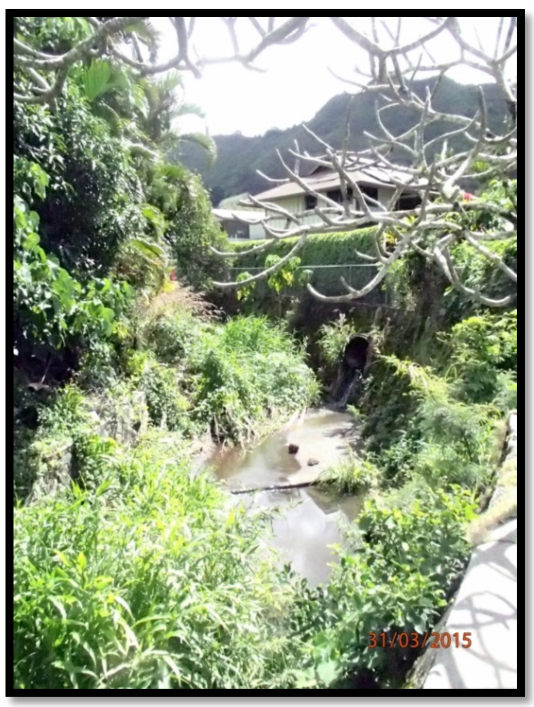

Figure 20: Looking upstream on Woodlawn Ditch from end of Kahiwa Place. Channelized section begins here. (G. Higashi, DAR photo)

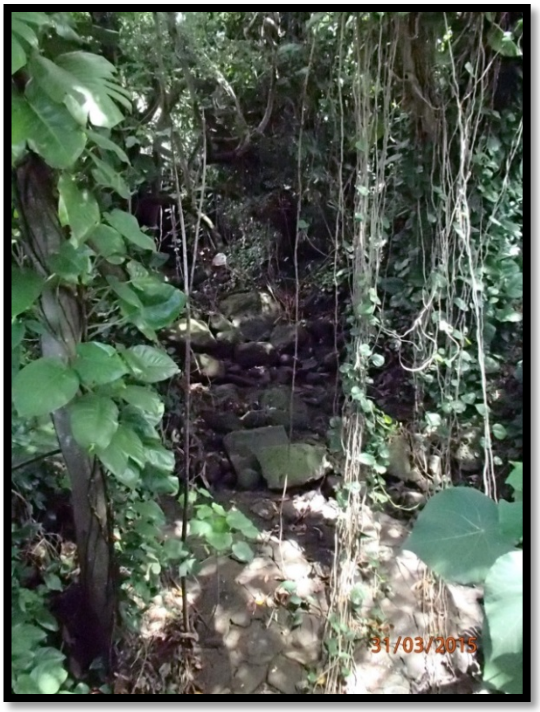

Figure 21: Looking upstream from the East Manoa Road and Akaka Place intersection. Stream is dry here. This is just above the Detention Basin site. (G. Higashi, DAR photo)

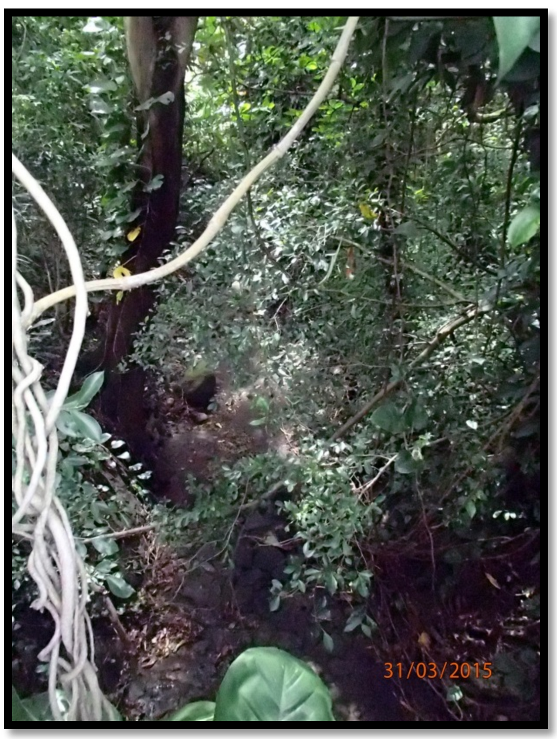

Figure 22: Looking upstream from the East Manoa Road and Akaka Place intersection. Stream is dry here. This is just above the Detention Basin site. (G. Higashi, DAR photo)

Site 5, Manoa Stream: Waihi Debris and Detention Basin

Segment ID: 53

Area Map:

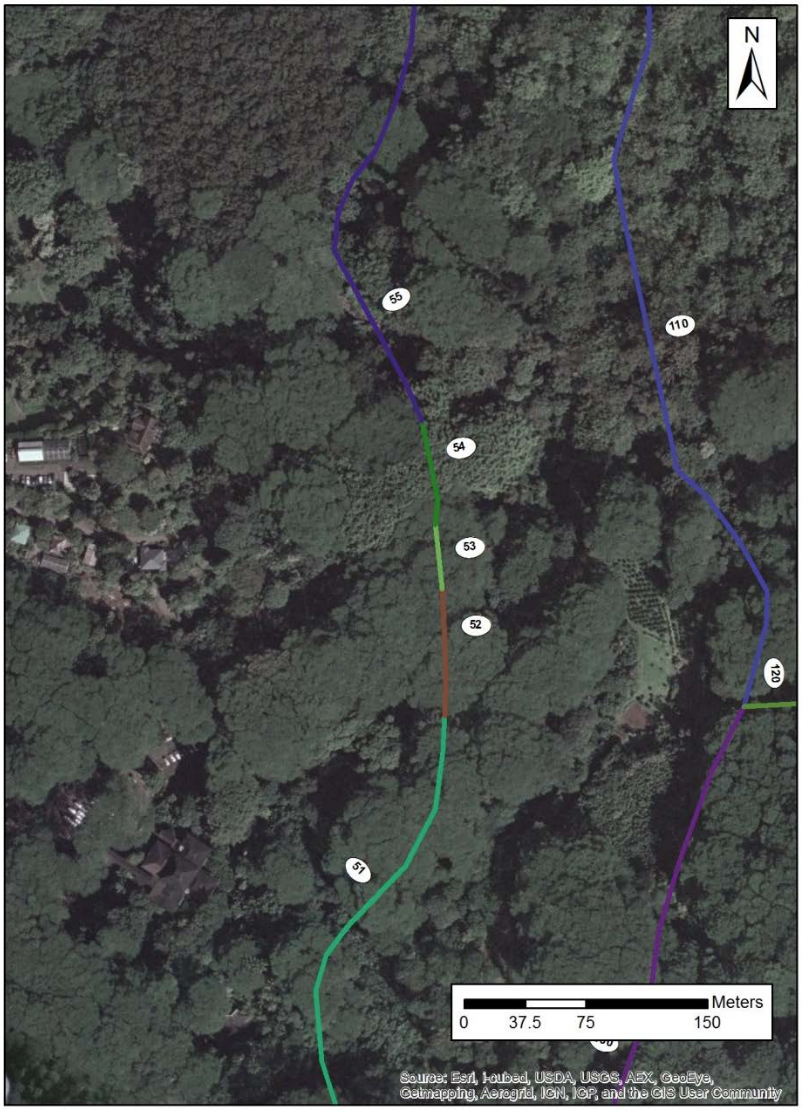

Figure 23: HSHEP segment numbers associated with the Waihi Debris and Detention Basin Site.

Site Description: Manoa Stream, in the vicinity of the Waihi Debris and Detention basin, is a relatively natural stream. We observed a range of substrate types from fine sand to large boulder, with run, riffle and pool habitats all present. This site is above the majority of the development found lower in the watershed and has large trees throughout its riparian zone. There is evidence of erosion scars from past flooding events and numerous large logs are found in the stream channel but in general the instream habitat would be considered good in comparison to much of the rest of Manoa Stream.

The debris and detention basin here will change instream habitat and likely capture substantial amounts of woody debris. The footprint of the detention berm will be expected to eliminate all instream habitats under both the Expected Condition and the Worst-Case Condition scenarios.

Figure 24: Downstream of the Waihi Detention Basin Site.

Figure 25: A plunge pool in the area of the Waihi Detention Basin Site.

Figure 26: Looking upstream toward Waihi Detention Basin Site. Much of the area ahead was impassable due to flood debris, with many logs across the stream.

Site 6, Manoa Stream: Waiakeakua Debris and Detention Basin

Segment ID: 82

Area Map:

Figure 27: HSHEP segment numbers associated with Waiakeakua Debris and Detention Basin Site.

Site Description: The tributary of Manoa Stream, in the vicinity of the Waiakeakua Debris and Detention basin, is a relatively natural stream. We observed a range of substrate types from fine sand to large boulder, with run, riffle and pool habitats all present. This site is above the majority of the development found lower in the watershed and has large trees throughout its riparian zone.

There is evidence of erosion scars from past flooding events and hau and bamboo are growing in the stream channel, but in general the instream habitat would be considered good in comparison to much of the rest of Manoa Stream.

The debris and detention basin here will change instream habitat and likely capture substantial amounts of woody debris. The footprint of the detention berm will be expected to eliminate all instream habitats under both the Expected Condition and the Worst-Case Condition scenarios.

Figure 28: Lower end of Waiakeakua Debris Basin. Note that much of the area is overgrown by Hau trees.

Figure 29: Upper end of Waiakeakua Debris basin.

Site 7, Palolo Stream: Waiomao Debris and Detention Basin

Segment ID: 214 and 215

Area Map:

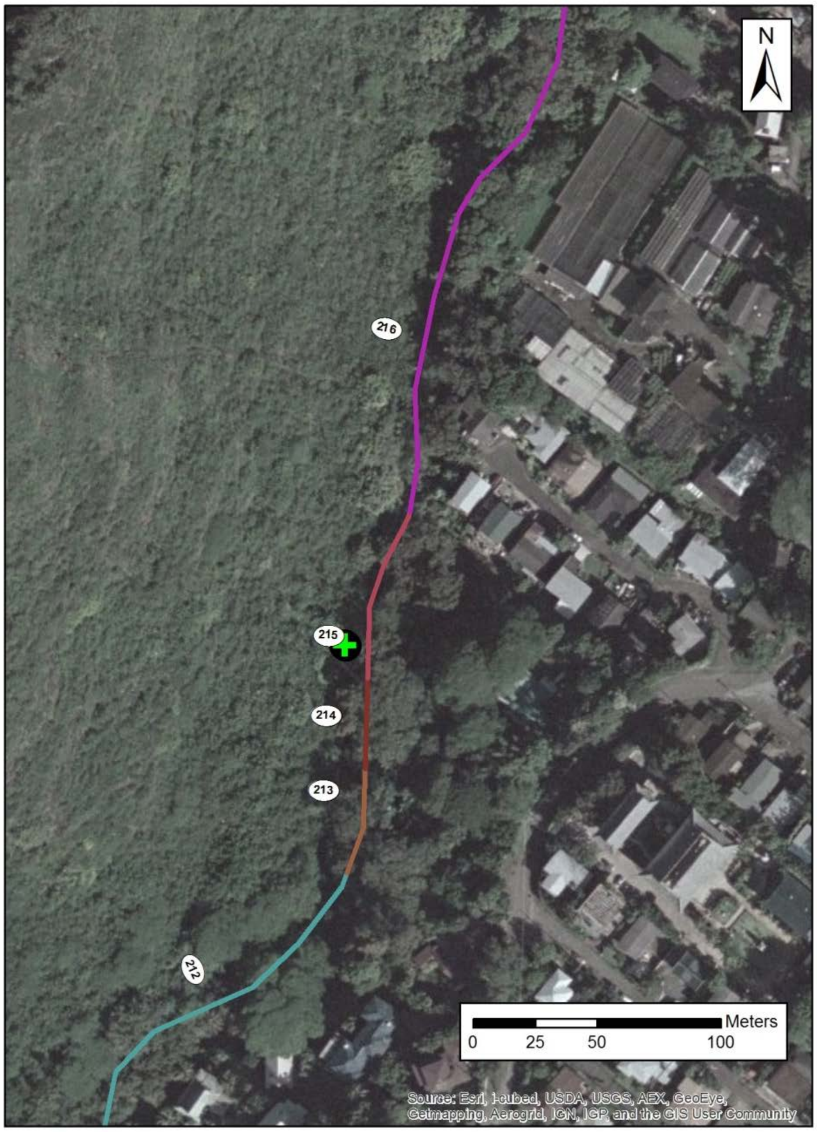

Figure 30: HSHEP segment numbers associated with Waiomao Debris and Detention Basin Site.

Site Description: The Waiomao tributary of Palolo stream, in the vicinity of the Waiomao Debris and Detention basin, is a relatively natural stream. We observed a range of substrate types from fine sand to large boulder, with run, riffle and pool habitats all present. This site has housing developments on its right bank looking upstream but still has large trees and bushes in much of its riparian zone. There is evidence of erosion scars from past flooding events and an old USGS gage is located in the stream channel at the site. Overall, the instream habitat would be considered good in comparison to much of the rest of Palolo stream.

The debris and detention basin here will change instream habitat and likely capture substantial amounts of woody debris. The footprint of the detention berm will be expected to eliminate all instream habitats under both the best professional judgment and the maximum impact scenarios. At this location, the area above the berm will be excavated to increase the detention volume of the basin and thus some habitat will be lost in this area also. Expected Condition expected a loss of approximately 50% of the habitat with the Worst-Case Condition scenario at 100% loss of habitat in the excavation area.

The old USGS gage will be removed during the construction of this project and as a result upstream passage will be improved for native migratory stream animals. Thus, there are both positive and negative impacts associated with the flood risk management project at this location.

Figure 31: Downstream of the Waiomao Tributary Detention Basin site.

Figure 32: Looking upstream into the Waiomao Tributary Detention Basin site.

Figure 33: The USGS gage in the Waiomao Tributary Detention Basin site. This old gage will be removed with the project and will no longer be a barrier to upstream animal passage.

Site 8, Palolo Stream: Pukele Debris and Detention Basin

Segment ID: 223

Area Map:

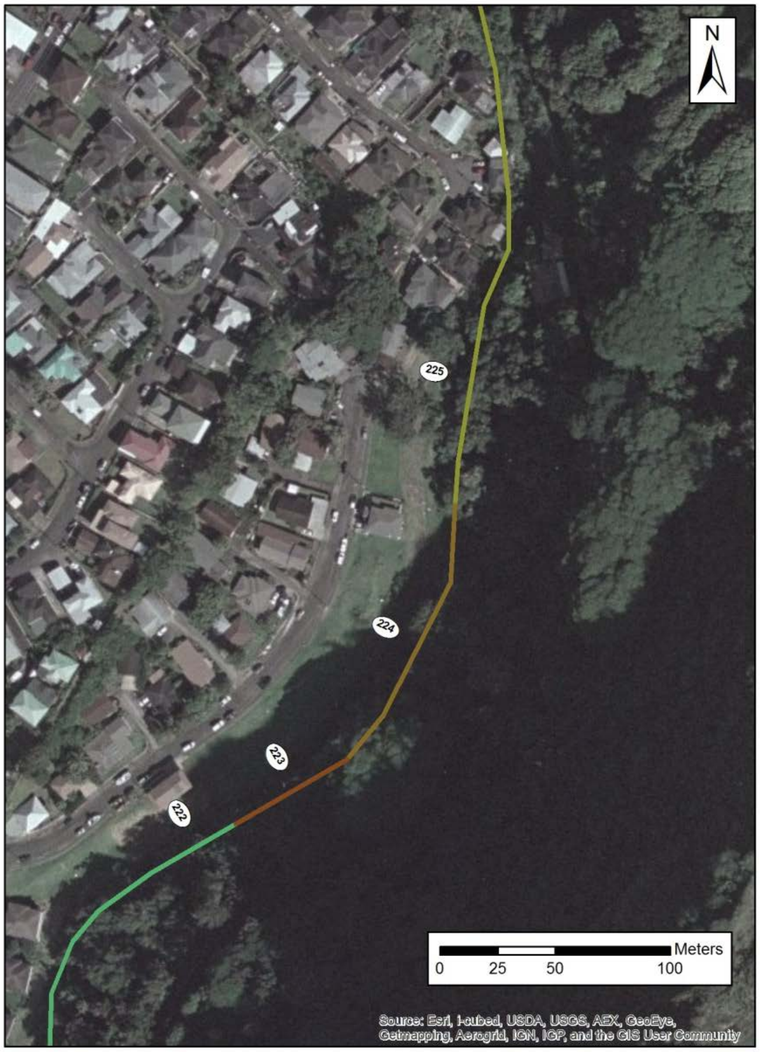

Figure 34: HSHEP segment numbers associated with Pukele Debris and Detention Basin Site.

No pictures available as we were unable to gain access to this site. It is modeled to be similar to the Waiomao Tributary site.

Site 9, Makiki Stream: Makiki Debris and Detention Basin

Segment ID: 304

Area Map:

Figure 35: HSHEP segment numbers associated with Makiki Debris and Detention Basin Site.

Site Description: Makiki stream, in the vicinity of the Makiki Debris and Detention basin, is a relatively natural stream. It is narrow with steep walls and we observed a range of substrate types from gravel to large boulder, with run, riffle and pool habitats all present. This site has large trees and bushes in much of its riparian zone. There is evidence of erosion scars from past flooding events. Overall, the instream habitat would be considered good in comparison to much of the rest of Makiki stream. We began our survey after the stream reemerged from being underground for a long section under Honolulu. Interestingly, we observed amphidromous animals as well as numerous introduced fishes in the area. This confirms that some native animals are able to travel underneath the city to reach the upper reaches of the stream.

The debris and detention basin here will change instream habitat and likely capture substantial amounts of woody debris. The footprint of the detention berm will be expected to eliminate all instream habitats under both the Expected Condition and Worst-Case Condition scenarios.

Figure 36: Downstream of Makiki Detention Basin Site.

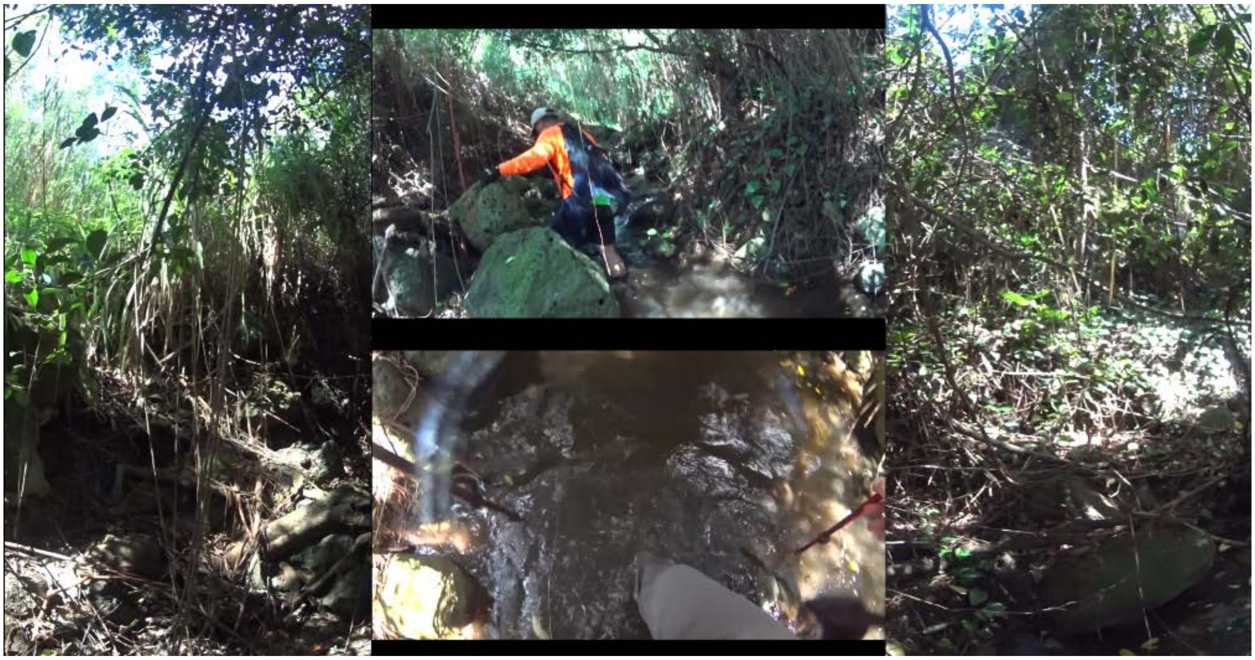

Figure 37: Near downstream end of Makiki Detention Basin Site.

Figure 38: Makiki Stream in the area of Makiki Detention Basin Site.

Site 10, Hausten Ditch: Hausten Ditch Detention Basin Intake

Segment ID: 500

Area Map:

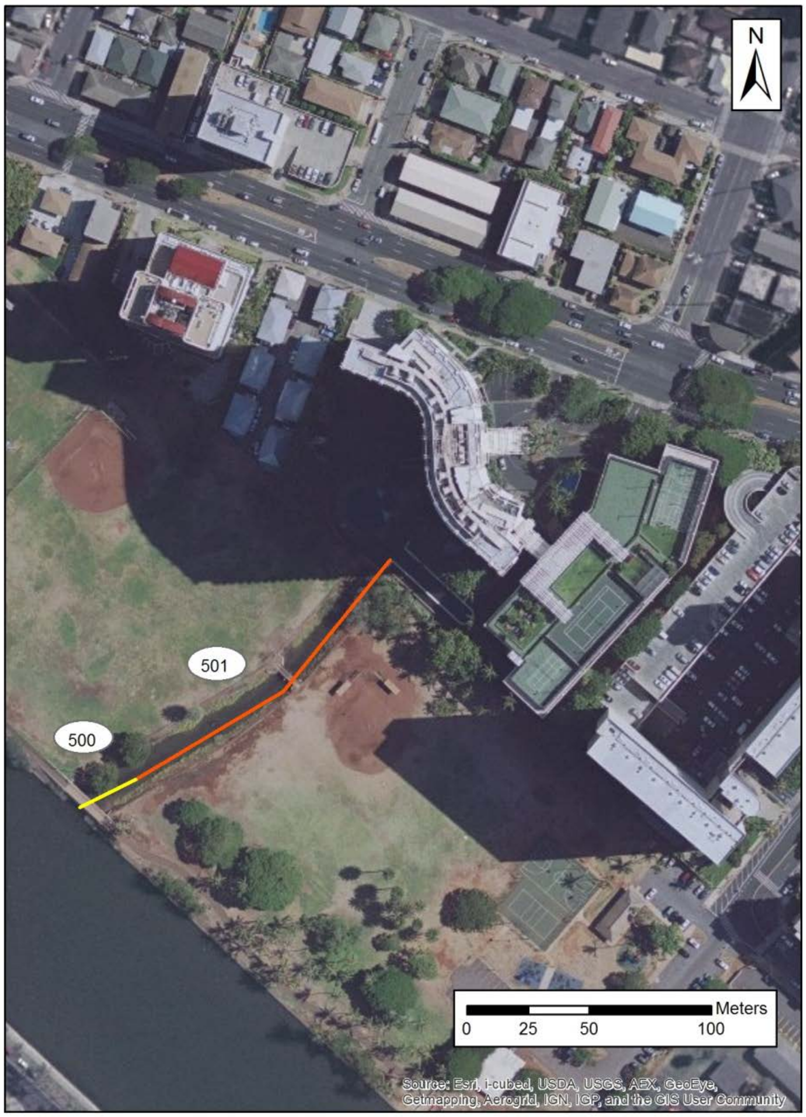

Figure 39: HSHEP segment numbers associated with Hausten Ditch Detention Basin Intake Site.

Site Description: Hausten Ditch is moderately wide at this location and the banks are covered with mangrove trees. The channel is constrained by man-made streambanks. The water is relatively slow moving and deep with mostly fine substrates. This area is tidally influenced and what hard substrates do exist appear to be highly embedded with fine sediment.