# Chapter 3: Water Quality Conditions

## 3.1 Explanation and Meaning of Water Quality Parameters

Measurements of stream water quality has focused on concentrations of nitrate (**$NO_3$)** ammonia (**$NH_4$)**, total dissolved nitrogen (**TDN**), total nitrogen (**TN**, includes all forms of nitrogen, including dissolved and solid components), phosphate (**$PO_4$)**, total phosphorus (**TP**, includes all forms of phosphorus, including both dissolved and solid components), and suspended sediment (Total Suspended Solids or **TSS**). Nitrate measurements are actually measurements of the sum of nitrate plus nitrite (**$NO_3$+$NO_2$**); however, the amount of nitrite is negligible. In reporting the concentrations (weight of pollutant per liter of water), the notation **$NH_4$ as N** or **$NH_4$-N** means that only the weight of nitrogen (N) is included; the weight of other atoms such as hydrogen or oxygen is not included.

Water quality monitoring in the Waiʻulaʻula watershed has focused on nitrogen (which comes in many forms) and phosphorus (which comes in several forms) because they encourage growth of algae. Too much algae makes the water cloudy and will eventually cause oxygen levels to decline. High levels of oxygen are needed for a health ecosystem.

In addition to the above, marine water quality measurements include dissolved silica and chlorophyll-a. The silica is not a pollutant. It is found in groundwater, so higher levels indicate greater groundwater influence. High levels of chlorophyll-a indicate that excessive levels of algae are growing in the water.

## 3.2 Availability of Data

The following data are available:

1) Older water quality data (1971-1989) collected by the U.S. Geological Survey (USGS) in the headwaters of Waikoloa Stream (Marine Dam gaging station 16758000).
2) Recent stream water quality data (2007-2009) collected by the MKSWCD at four locations with autosamplers. Grab sample data are available for several additional locations.
3) Water quality data for runoff from parking lots and roads.
4) Discharge data at most locations where stream water quality data were collected. Discharge data were used to calculate discharge-weighted average concentrations and to calculate nutrient loads.
5) Marine water quality data (2006-2008) collected by the Hawaiʻi Department of Health (DOH).

6) Biological surveys.
7) Trace metals in stream and roadside sediment.

*<u>Older water quality data</u>*: Water quality data were collected at the Marine Dam gage station (16758000) between 1971 and 1989. These data were collected by the USGS Water Resources Branch. Along with physical parameters like temperature and discharge, nutrients and trace element concentrations were measured on fourteen occasions. Nutrient concentrations were all very low (near detection limits) except for orthophosphate which showed two elevated readings.

*<u>New water quality data</u>*: Autosamplers were used to collect stormwater runoff that was analyzed for nutrient and suspended sediment concentrations. The autosamplers were located on Waikoloa stream at the Marine Dam ("upper" site), Waikoloa stream downstream of Waimea town ("middle" or "Sandalwood" site), and Waiʻulaʻula stream just upstream of the ocean entry ("lowest" or "ocean entry" site) (Figure 24). Data represent eleven storm events that occurred between November 2007 and February 2009. For one of these storms, autosampler data was also collected from Makeāhua stream just upstream at of its entry into Pelekane Bay ("Pelekane" site). The Makeāhua/Pelekane watershed is similar to the middle and lower sections of the Waiʻulaʻula watershed, but it is denuded by overgrazing and fire. It represents the worst case scenario that we are trying to prevent in the Waiʻulaʻula watershed. Grab samples of urban storm water runoff were collected on four occasions from sites in Waimea town.

The USGS makes routine measurements of streamflow (discharge) at the Marine Dam site. At the other autosampler sites, approximate estimates of stream discharge have been made on the basis of water level measurements. Measuring flow data at the same time that nutrient concentrations are measured permits us to calculate nutrient fluxes. Flux can be viewed as the amount of substance passing a point on the stream in a given period of time. Multiplying our concentrations (mass / volume) by flow rate (in volume / time) gives flux (mass / time).

Drainage basins contributing flow to the four sampling sites are very different. The forested Marine Dam basin (865 ac.) is comprised almost exclusively of protected headwater bog. The Sandalwood basin (2,037 ac.) drains much of Waimea Town and includes the Marine Dam basin. As discussed elsewhere in this report, the Waikoloa stream is affected by diversions. Waiʻulaʻula and Pelekane basins (associated with the two autosamplers near sea-level) cover the entire watersheds and contain a variety of land covers and land uses. Both basins include a large amount of ranch lands. Table 2 shows percent land cover of each of the four drainage basins. Land cover was derived from 2001 NOAA Coastal Change Analysis Program (C-CAP) data.

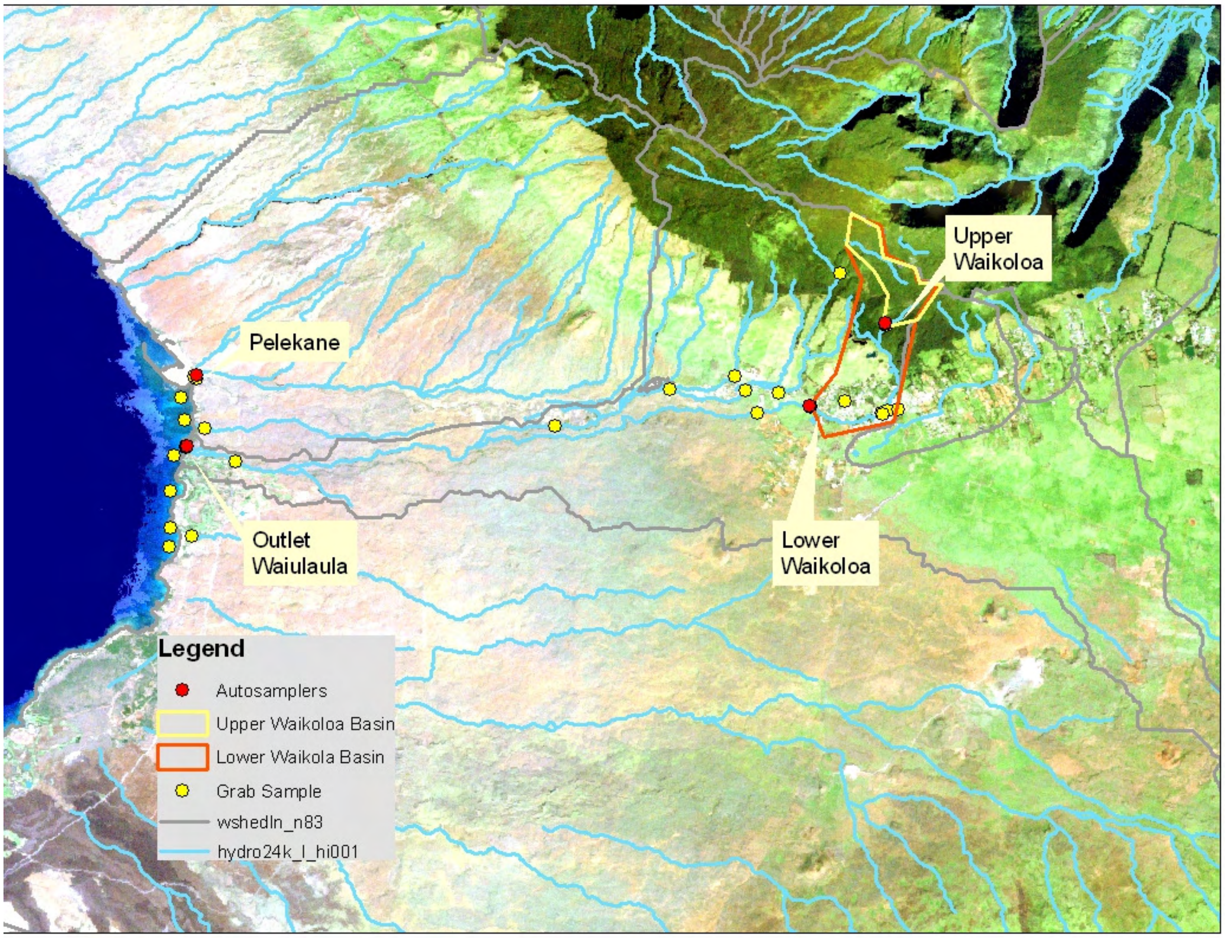



**Figure 24: Sample Locations**

**Table 2: Land Cover in Four Drainage Basins**

| | Waiulaula above Marine Dam | Waiulaula above Sandalwood | Waiulaula at Ocean | Pelekane |
|---|---|---|---|---|
| High intensity development | | 5% | 1% | 0% |
| Low intensity development | | 10% | 5% | 1% |
| Cultivated | | 1% | 1% | 0% |
| Grass | 2% | 42% | 58% | 72% |
| Evergreen Forest | 98% | 36% | 26% | 5% |
| Scrub/Shrub | trace | 5% | 5% | 6% |
| Bare | | 0% | 4% | 16% |
| Water | | 1% | trace | 0% |
| SUM | 100% | 100% | 100% | 100% |

## 3.3 Water Quality Standards

In the state of Hawaiʻi, minimum water quality standards (Chapter 11-54, HAR) are established by the Department of Health under the provisions of the Clean Water Act. These standards are intended to protect designated uses of streams and marine waters. (See Section 2.2.9.10 in the previous chapter for a discussion of classification and designated uses of waters within the Waiʻulaʻula watershed and immediately offshore.)

Nutrient and sediment standards applicable to all Waiʻulaʻula watershed streams are listed in Table 3. There are several additional standards:

- pH should not exceed 8.0, be lower than 5.5, or deviate more than 0.5 units from ambient conditions.
- Dissolved oxygen concentrations should not be less than 80% of saturation.
- Specific conductance should not be more than 300 umho/cm. [Note: umho/cm is a unit of electrical resistance. Very pure water does not conduct electricity as well as salty water.]
- Temperature should not vary more than 1 degree C from ambient conditions.

Most of the standards are based on the geometric mean of all samples taken within a relatively recent period (say five years). If there are *n* measurements on a given stream, the geometric mean is equal to the $n^{th}$ root of all the measurements multiplied together. For example, if there are three measurements with values of 2, 3, and 20, then the geometric mean is equal to $(2*3*20)^{1/3}$. Compared to an arithmetic average, the geometric mean is less influenced by occasional very large values. There are certain protocols that are used to officially determine if a water body meets standards. These procedures include having a sufficiently large number of recent samples, more than one sampling site on a stream, and using strict quality assurance protocols including a certified laboratory. The water quality measurements undertaken as part of this watershed assessment were not intended to be used for official determination of whether water bodies of interest meet regulatory standards. Thus, although measurements are compared to standards, this does not constitute official evaluation of whether the water bodies are impaired.

**Table 3: Water Quality Criteria for Streams**

| Parameter | Geometric mean not to exceed the given value | Not to exceed the given value more than ten percent of the time | Not to exceed the given value more than two percent of the time |
|---|---|---|---|
| Total Nitrogen (mg /L) | 0.250*<br>0.180** | 0.520*<br>0.380** | 0.800*<br>0.600** |
| Nitrate + Nitrite (mg/L-N) | 0.070*<br>0.030** | 0.180*<br>0.090** | 0.300*<br>0.170** |
| Total Phosphorous (mg/L-P) | 0.050*<br>0.030** | 0.100*<br>0.060** | 0.150*<br>0.080** |
| Total Suspended Solids (mg/L) | 20.0*<br>10.0** | 50.0*<br>30.0** | 80.0*<br>55.0** |
| Turbidity (N.T.U.) | 5.0*<br>2.0** | 15.0*<br>5.5** | 25.0*<br>10.0** |

*standard applicable during rainy (wet) season of November 1 through April 30

**standard applicable during dry season of May 1 through October 31

Table 4 lists nutrient and sediment standards applicable to the marine waters immediately offshore of the watershed (both A and AA waters). There are several additional standards:

- pH should not deviate more than 0.5 units from 8.1, unless affected by freshwater discharges, in which case pH must not be lower than 7.0.
- Dissolved oxygen concentrations should not be less than 75% of saturation.
- Salinity should not vary more than 10% from what is expected for oceanographic conditions, seasonal variations, or hydrologic inputs.
- Temperature should not vary more than 1 degree C from ambient conditions.

**Table 4: Open Coastal Waters Water Quality Criteria**

| Parameter | Geometric mean not to exceed this value |
|---|---|
| Total Dissolved Nitrogen* | 0.10 mg/L |
| Ammonia Nitrogen ($NH_4$) | 0.0025 mg/L-N |
| Nitrate + Nitrite Nitrogen* | 0.0045 mg/L-N |
| Total Dissolved Phosphorous* | 0.0125 mg/L |
| Phosphate* | 0.005 mg/L |
| Chlorophyll a | 0.30 ug/L |
| Turbidity | 0.10 N.T.U. |

If salinity is less than or equal to 32 parts per thousand, this parameter shall be related to salinity using a regression equation specified in HAR 11-54-6, pages 47-48.

Chapter 11-54, HAR also provides freshwater and marine standards relating to toxic substances (pesticides, heavy metals, organic solvents) and bottom sediments. These are not believed to be a problem for the Waiʻulaʻula watershed. It is unlikely that bottom sediments in Pelekane Bay meet standards, but that is outside the scope of this report.

## 3.4 Stream Data (nutrient and sediment concentrations)

### 3.4.1 Observed Concentrations

Autosamplers were set to collect water samples whenever the water level in the stream rose rapidly and then every 30-60 minutes thereafter. For each storm events, 24 one-liter samples were collected over a 12 to 20 hour period. To reduce costs, only 8-10 of these bottles were sent to the laboratory for analysis. Typically, bottles were selected based on turbidity and with a view towards being able to characterize changes over time. For example, early in the storm, when turbidity changed rapidly, every bottle would be selected. Late in the storm, when turbidity changed slowly, every third bottle might be selected. Discharge-weighted average concentrations were then calculated for each runoff event and autosampler location. Discharge-weighted averages are also known as the “event mean concentration” or EMC.[6] For

[6] The following procedure was used to obtain the EMC average. For each sample, the concentration (weight of pollutant per unit volume) was multiplied by the streamflow rate (volume of water per unit time) times the length of time represented by that sample (typically the time between successive samples). The resulting number was summed across samples, and then divided by the total volume of flow for that event.

each runoff event, the EMC is the total load of pollutant (amount measured as a weight) divided by the flow volume. Streamflow data are needed to make EMC calculations. Streamflow data for the Marine Dam were obtained from the USGS. Flow data at the other autosampler sites were obtained from measurements of water depth (which is recorded continuously by the autosampler) and the Manning equation. Streamflow data from the Sandalwood, Waiʻulaʻula, and Pelekane sites should be considered approximate.

TSS and TP increase when stream discharge increases (correlation coefficient of 0.81 for TSS and 0.78 for TP).

There are several factors that should be taken into consideration when comparing nutrient concentrations and fluxes at the upper site (above town) and the Sandalwood site (below town). First, water is diverted from Waikoloa stream immediately downstream of the upper site. Normally, the stream is completely impounded by the dam and all water is diverted into the Department of Water Supply intake. During a storm event, the water will rise and eventually overtop the dam. Only after the dam is overtopped will water flow down the channel towards Waimea. Second, it is likely that Waikoloa is a losing stream between the upper autosampler and Waimea Town. This means that the streambed leaks and some of the streamwater (along with whatever is dissolved in it) filters into the ground and does not make it to the Sandalwood autosampler site. The exact amount that is lost is unknown. It is noteworthy, however, that for the three events with data (12/6/07, 12/16/07 and 1/26/08), the stormflow volume at the Sandalwood site is only 3% more than the streamflow volume at the upper gage. Even taking into account the fact that the streamflow data at the Sandalwood site are not very accurate, it is clear that much of the runoff from the upper forested part of Waikoloa stream is not making it down to Waimea Town. This issue is revisited in the Monitoring chapter (Chapter 6).

### 3.4.2 Are Streams Polluted?

Measured sediment and nutrient concentrations were compared to water quality standards in order to evaluate whether or not streams are polluted (Tables 5 and 6).

At Marine Dam (where Waikoloa stream exits the high-elevation forest), the stream has relatively low concentrations of nitrate, ammonia, and orthophosphate ($PO_4$). The geometric mean of measured nitrate concentration was only 23% of the water quality standard, and mean $PO_4$ was only 9% of the standard. There is no standard for ammonia. The geometric mean of total nitrogen concentration (sum of particulate and dissolved forms) was 17% higher than the standard. The geometric mean of total phosphorus (TP) concentration was 30% lower than the standard. Mean suspended solids (sediment concentration) were only 50% of the standard.

Further down on the same stream, concentrations were measured at the Sandalwood site, which is at the downstream edge of Waimea Town. In comparison to the Marine Dam site, ammonia concentrations doubled, total phosphorus concentrations (TP) more than doubled, and nitrate concentrations quadrupled. The average nitrate concentration just barely exceeded the water quality standard.  The TP concentration was nearly twice the allowable amount. Sediment concentrations at Sandalwood were higher than at the Marine Dam.  The Sandalwood sediment concentrations were below the standard, although just barely.

Much further downstream, an autosampler was installed on the Wai'ula'ula Stream a short distance above where it enters the ocean.  At this location, sediment, ammonia, nitrate, and total phosphorus concentrations were low and within acceptable limits.  Nitrate was less than half of what is allowed; sediment and total phosphorus were about 30% lower than what is allowed.  Total nitrogen was high, however, with measured concentrations nearly twice what is allowed.

Only one runoff event was captured by the Pelekane autosampler, which is located several hundred yards above where the stream enters the ocean.  Sediment and nutrient concentrations were incredibly high.  The sediment concentration was 150 times greater than what is allowed, and the total nitrogen concentration was 240 times greater than what is allowed.  The corresponding figures for nitrate and total phosphorus are 11 times and 40 times greater, respectively.

At all sites, the majority of phosphorus (>86%) was present as particulate matter, with only a small amount ($\leq$14%) present in dissolved form.  This is not surprising, as streams on Hawai'i Island (and elsewhere) have a majority of phosphorus present in particulate form (Michaud and Weigner 2011).   No analyses were conducted to determine whether N or P is the limiting nutrient.  A study conducted that examined four Oahu streams (Larned and Santos 2000) found that they were P limited.  There is no guarantee, however, the Wai'ula'ula is also P limited.

Dissolved nitrogen can be present in three different forms: organic (DON), nitrate, nitrite, and ammonia.  Of these, nitrite is rarely present under conditions experienced in the watershed.  While dissolved organic nitrogen is abundant, it is not immediately available to algae, whereas nitrate and ammonia are utilized directly by algae.  Ammonia is toxic to fish and aquatic invertebrates.

The three sites on the Wai'ula'ula/Waikoloa stream differ in the proportions of the various forms of dissolved nitrogen.  The Sandalwood site just below Waimea Town has the lowest proportion of DON (54% of dissolved nitrogen is organic) and the highest proportion of nitrate (31% of dissolved nitrogen is nitrate).

Most particulate nitrogen is present as living OR partially decomposed dead organisms (including plankton and partially decomposed vegetation).

**SIDEBAR: Understanding Nitrogen**

**Table 5: Nutrient and Sediment Concentrations in Samples Collected by Autosamplers. Values are discharge-weighted (EMC).**

| SITE | Date | TSS mg/l | TDN mg/l - N | TN mg/l - N | $NO_3$+$NO_2$ mg/l – N | $NH_4$ mg/l-N | $PO_4$ mg/l-P | TP mg/l-P | Runoff $m^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Marine Dam (forest) | 1-Nov-07 | 9 | 0.233 | *0.343* | 0.020 | 0.019 | 0.005 | 0.047 | 25,000 |
| Marine Dam (forest) | 6-Nov-07 | 17 | 0.223 | *0.399* | 0.010 | < 0.014 | 0.007 | 0.056 | 25,000 |
| Marine Dam (forest) | 14-Nov-07 | 5 | 0.077 | *0.140* | 0.015 | 0.0113 | 0.005 | 0.019 | 18,000 |
| Marine Dam (forest) | 3-Dec-07 | 8 | 0.191 | *0.300* | 0.015 | 0.0169 | 0.004 | 0.025 | 42,000 |
| Marine Dam (forest) | 5-Dec-07 | 24 | 0.230 | *0.373* | *0.012* | 0.011 | 0.0026 | 0.063 | 140,000 |
| Marine Dam (forest) | 16-Dec-07 | 32 | 0.148 | *0.372* | 0.016 | 0.023 | 0.004 | 0.120 | 210,000 |
| Marine Dam (forest) | 26-Jan-08 | 2 | 0.187 | *0.229* | 0.025 | 0.021 | 0.004 | 0.007 | 23,000 |
| **geometric mean** | | **10** | **0.174** | ***0.292*** | ***0.016*** | **0.014** | **0.0043** | **0.035** | |
| Sandalwood | 22-Nov-07 | 49 | 0.251 | *0.652* | 0.121 | 0.017 | 0.015 | 0.164 | 100,000 |
| Sandalwood * | 4-Dec-07 | 8 | 0.348 | *0.505* | 0.110 | 0.152 | 0.026 | 0.067 | n/a |
| Sandalwood | 6-Dec-07 | 37 | 0.303 | *0.576* | 0.080 | 0.017 | 0.012 | 0.141 | 167,000 |
| Sandalwood | 16-Dec-07 | 42 | 0.188 | *0.487* | 0.033 | 0.014 | 0.007 | 0.194 | 203,000 |
| Sandalwood | 26-Jan-08 | 3 | 0.215 | *0.275* | 0.064 | 0.033 | 0.010 | 0.019 | 15,000 |
| **geometric mean** | | **18** | **0.255** | ***0.480*** | **0.074** | **0.029** | **0.013** | **0.089** | |
| Coastal Outlet | 17-Jan-09 | 21 | 0.442 | 0.826 | 0.191 | 0.025 | < 0.003 | 0.046 | 48,000 |
| Coastal Outlet** | 24-Jan-09 | 8 | 0.225 | 0.339 | 0.005 | < 0.014 | < 0.003 | 0.035 | 40,000 |
| Coastal Outlet | 3-Feb-09 | 12 | 0.244 | 0.415 | 0.024 | 0.029 | 0.004 | 0.027 | 132,000 |
| **geometric mean** | | **13** | **0.290** | **0.488** | **0.028** | **0.017** | **0.002** | **0.035** | |
| Pelekane | 6-Dec-07 | **3045** | **1.93** | ***59.6*** | **0.77** | **0.22** | **0.046** | **1.98** | 69,000 |
| Water quality standard*** | | **20** | **n/a** | **.250** | **.070** | **n/a** | **n/a** | **.050** | **n/a** |

* arithmetic average of 2 grab samples ** arithmetic average of 6 autosamples *** Wet season geometric mean should not exceed.

TN values in italics are estimated based on TSS and TDN concentrations.

Table 6 summarizes whether or not sediment and nutrient concentrations are high enough to impair water quality. This interpretation is based on comparing the measured value (geometric mean of measurements from several runoff events) to the water quality standards. There were 7 runoff events measured at Marine Dam, 5 events at Sandalwood, 3 events at the watershed outlet, and 1 event at Pelekane. In this table "impairment" is meant in a general sense, and not in the sense of a formal assessment by the Hawaiʻi Department of Health.

**Table 6: Summary of Stream Impairments for Nutrient and Sediment Based on Monitoring Data**

| **Site** | **TSS (sediment)** | **Total Nitrogen** | **Nitrate** | **Total Phosphorus** |
|---|---|---|---|---|
| **Marine Dam (above Waimea)** | Not impaired<br><br>(measured value below the standard) | Could be impaired<br><br>(measured value near the standard) | Not impaired<br><br>(measured value well below standard) | Probably not impaired<br><br>(measured value below standard, but not by much) |
| **Sandalwood (below Waimea)** | Could be impaired<br><br>(measured value near the standard) | Impaired<br><br>(measured value almost double the standard) | Could be impaired<br><br>(measured values near the standard) | Impaired<br><br>(measured value almost double the standard) |
| **Watershed outlet** | Not impaired<br><br>(measured value below the standard) | Impaired<br><br>(measured value almost double the standard) | Not impaired<br><br>(measured values below standard) | Probably not impaired<br><br>(measured value below standard, but not by much) |
| **Pelekane** | Very polluted<br><br>(Exceeds standard by 2 orders of magnitude) | Very polluted<br><br>Exceeds standard by 2 orders of magnitude | Very polluted<br><br>Exceeds standard by 1 order of magnitude | Very polluted<br><br>Exceeds standard by 2 orders of magnitude |

## 3.5 Urban Runoff (nutrient and sediment concentrations)

### 3.5.1 Observed Concentrations

Nine samples of urban storm runoff were collected by taking grab samples of flowing water in parking lots, storm water running off of roads, or from pipes that collect parking lot/road runoff (Table 7). All sites were located in Waimea, and samples were collected between November 2008 and April 2009.

### 3.5.2 How Polluted is Waimea's Urban Runoff?

Based on a limited amount of data, it appears likely that runoff from high-use paved areas exceeds water quality criteria for sediment (by a factor of five), total phosphorus (by a factor of four), total nitrogen (by a factor of three) and nitrate (measured values are only slightly greater than the standard). These results are not surprising as urban storm runoff is usually high in sediment and nutrients. The urban runoff concentrations can also be compared to concentrations measured in Waikoloa Stream immediately downstream of Waimea (at the middle or Sandalwood autosampler). Compared to the stream, the urban runoff was more enriched in sediment (by a factor of six), orthophosphate (by a factor of 5), total phosphorus (by a factor of 2.3), ammonium (by a factor of 1.7), and total nitrogen (by a factor of 1.7). The urban and stream samples were taken on different days, so results could very well be different if stream and urban samples were taken on the same day, or if more urban samples were collected at more times in more locations. These limitations notwithstanding, the data that are available show that runoff from paved urban areas has high concentrations of sediment and nutrients, particularly particulate nutrients. Further, it appears that the runoff from high-use paved areas is more polluted than the water in the stream.

Studies on Oahu and on the mainland have shown that urban runoff often contains heavy metals and occasionally pesticides, but similar measurements of Waimea's stormwater have not been made. Measurements have been made in Waimea's roadside sediment, however. These data are discussed in section 3.8.

### 3.5.3 First Flush

"First flush" occurs when the initial runoff washes pollutants off roads and fields, delivering a majority of pollutants in the early part of a runoff event (when water levels are still rising). To see if this was occurring in the Waikoloa Stream, autosampler data from the Marine Dam watershed (forested higher-elevation area) and Sandalwood watershed (includes Waimea urban core) were analyzed using the dimensionless mass-volume (MV) method. The first flush

**Table 7: Grab Samples of Urban Storm Runoff Collected from Waimea Parking Lots and Roads**

| Location | Date | TSS mg/L | TDN mg/L-N | TN* mg/L-N | $NO_3 + NO_2$ mg/L-N | $NH_4$ mg/L-N | $PO_4$ mg/L-P | TP mg/L-P |
|---|---|---|---|---|---|---|---|---|
| KTA parking lot white pipe | 11/18/08 | 32 | 0.14 | *0.30* | 0.008 | <.0014 | 0.007 | 0.061 |
| Comm Ed Ctr | 11/18/08 | 378 | 1.03 | *5.56* | 0.502 | 0.165 | 0.127 | 1.008 |
| KTA backlot (parking) | 11/18/08 | 550 | 1.07 | *8.33* | 0.149 | 0.081 | 0.817 | 0.908 |
| Paniolo Parking Lot | 11/18/08 | 44 | 0.55 | *0.83* | 0.055 | 0.036 | 0.091 | 0.242 |
| Community. Ed Big Pipe | 1/11/09 | 35 | 0.22 | 0.56 | 0.068 | 0.096 | 0.040 | n/a |
| Community Ed Big Pipe | 12/11/08 | 368 | 0.47 | 3.35 | 0.148 | 0.062 | 0.037 | 0.834 |
| Community Ed Big Pipe | 4/15/09 | 97 | 1.87 | 2.95 | 0.557 | 0.164 | 0.031 | 0.359 |
| Mamalahoa Hwy KTA side | 11/18/08 | 139 | 0.59 | *1.76* | 0.084 | 0.091 | 0.089 | 0.482 |
| Mamalohoa Highway site #2 | 11/18/08 | 49 | 0.39 | *0.69* | 0.048 | 0.059 | 0.044 | 0.152 |
| **geometric mean** | | **111** | **0.54** | **0.83** | **0.10** | **0.05** | **0.05** | **0.21** |
| *compare to* | | | | | | | | |
| geometric mean of stream at Sandalwood autosampler | | 18 | 0.26 | 0.48 | 0.07 | 0.03 | 0.01 | 0.09 |
| wet season geometric mean should not exceed | | 20 | n/a | 0.25 | 0.07 | n/a | n/a | 0.05 |

* Values in italics are based on measured TDN values and estimated PN values.

phenomenon was not seen in the majority of storms. However, a first flush of total suspended solids (TSS) and ammonia occurred during the 11/22/07 storm and a first flush of $NH_4$ occurred during the 11/14/07 storm. In these cases, 25% to 50% of the pollutants were seen in the first 20% of stream flow.

Some storm events have data for both the Marine Dam and Sandalwood sites. For these storms, nitrogen pollutants were delivered earlier (relative to the onset of flooding) at the Sandalwood site compared to the upper site in the forest. This could indicate that in Waimea there is nitrogen on the surface of the ground (for example, fertilizer or animal feces) that is quickly washed off at the beginning of the storm. This interpretation is uncertain, however, because results were mixed for TP and TSS.

### 3.5.4 Variations in the form of nitrogen

Nitrogen can occur in several different forms. The three basic categories are dissolved organic nitrogen, dissolved inorganic nitrogen, and particulate nitrogen. Dissolved inorganic nitrogen can be present as nitrate (most stable form), nitrite (rarely present), ammonia (unstable form found in sewage and fertilizer). Dissolved organic nitrogen consists of carbon-rich compounds of biological origin. Pound for pound, the common forms of inorganic nitrogen (nitrate and ammonia) have a greater influence on ecosystems than an equivalent amount of organic nitrogen. There is more organic nitrogen than inorganic nitrogen, however. Nitrogen readily changes from one form to another and can be transformed to a gas through a process called denitrification. Denitrification typically occurs when there is little oxygen present and results in loss of nitrogen to the atmosphere. High concentrations of ammonia are stressful to aquatic life. Notably, ammonia concentrations in Kawaihae Bay at Waiʻulaʻula exceed marine water quality standards. (There are no ammonia limits for streams.) In the Bay, there is more ammonia than nitrate, whereas in the stream there is more nitrate than ammonia. When oxygen is present, ammonia tends to be converted to nitrate. The higher proportion of ammonia in Kawaihae Bay at Waiʻulaʻula suggests that an ammonia source could be nearby.

In the stream, different sites have different concentrations of the various types of nitrogen (Table 8). Compared to the other sites, the forest site has the lowest concentration of nitrate and ammonia. The watershed outlet has the highest concentration of dissolved organic nitrogen. There are also differences in the *proportions* of the three kinds of dissolved nitrogen. In comparison to the other sites, the urban site has the greatest proportion of nitrate and ammonia (as a percentage of total dissolved nitrogen).

**Table 8: Concentrations of Various Forms of Dissolved Nitrogen**

Values are concentrations (geometric mean of all days with measurements) in units of mg/l as N. The value in parentheses is the percentage of that station's total dissolved nitrogen.

| | Ocean (Waiʻulaʻula Bay) | Stream at watershed outlet | Urban runoff | Sandalwood (below Waimea) | Marine Dam (edge of forest) |
|---|---|---|---|---|---|
| Nitrate | **0.005** (5%) | **0.028** (10%) | **0.10** (19%) | **0.074** (29%) | **0.016** (9%) |
| Ammonia | **0.007** (7%) | **0.017** (6%) | **0.05** (9%) | **0.029** (11%) | **0.014** (8%) |
| Organic | **0.088** (88%) | **0.245** (84%) | **0.39** (72%) | **0.152** (60%) | **0.144** (83%) |

## 3.6 Marine Data (nutrient, sediment, and algae concentrations)

### 3.6.1 Observed Concentrations

During the period July 2006 – April 2008, DOH made frequent measurements of water quality at a number of coastal sites. Measurements in the nearshore waters of Kawaihae Bay at Waiʻulaʻula were taken on thirty-three separate days. Average values (geometric mean) are shown in Table 9; a similar table showing variability over time is found in the appendix.

The water quality measurements included suspended sediment, several types of nutrients, dissolved silica, and chlorophyll-a. The silica is not a pollutant. It is found in groundwater, so higher levels indicate greater groundwater influence. Nutrients are substances that encourage the growth of algae. Measurements were made of two types of dissolved nutrients (ammonia and the combination of nitrate+nitrite). Total nitrogen (or total phosphorus) is a measurement of all possible forms of dissolved and solid nitrogen (or phosphorus). High levels of chlorophyll-a indicate that excessive levels of algae are growing in the water. Too much algae makes the water cloudy, blocking sunlight needed by coral. Very high levels of algae result in too little oxygen in the water.

Marine algal growth could either be phosphorus-limited or nitrogen-limited. Studies that would shed light on this issue have not been conducted at Waiʻulaʻula, but a study conducted on Oahu (Larned 1998) found that marine macroalgae in Kaneohe Bay were N limited. The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus can shed light on nitrogen and phosphorus dynamics. No measurements of dissolved inorganic phosphorus have been made at Waiʻulaʻula, however, presumably because there are no regulatory standards for it. The observed TN:TP ratio is 15:8, which is a typical value for coastal waters. It would be more informative to examine the ratio of dissolved N to dissolved P, but the necessary data are not available.

**Table 9: Geometric Mean of Ocean Water Quality Measurements Made Near the Mouth of the Waiʻulaʻula River and at Several Comparison Sites**

The water quality standards listed in the table are the ones that should not be exceeded if the salinity is > 32 parts per thousand. The TP and TN standards are for filtered samples, and it is presumed that TP and TN data are for filtered samples.

| | TSS (mg/L) | Ammonia (mg/L-N) | Nitrate + Nitrite (mg/L-N) | TN (mg/L -N) | TP (mg/L -P) | Filtered Silica (mg/L) | Chlorophyll 'a' (ug/L) |
|---|---|---|---|---|---|---|---|
| **Kawaihae Bay at Waiʻulaʻula** (Leeward Hawaiʻi) | 9.26 | 0.007 | 0.005 | 0.10 | 0.014 | 0.26 | 0.62 |
| | | | | | | | |
| **Waiʻulaʻula water quality standard** | none | 0.0025 | 0.0045 | 0.1 | 0.0125 | none | 0.3 |
| | | | | | | | |
| **Pelekane Bay** (Leeward Hawaiʻi) | 44.28 | 0.038 | 0.050 | 0.26 | 0.050 | 1.60 | 3.28 |
| **Hapuna Beach** (Leeward Hawaiʻi) | 9.59 | 0.004 | 0.060 | 0.15 | 0.019 | 1.45 | 0.36 |
| **Hilo Bay** (Lighthouse) (Windward Hawaiʻi) | 13.01 | 0.010 | 0.025 | 0.16 | 0.021 | 1.99 | 1.77 |
| **Kihei** (South) (Leeward Maui) | 16.93 | 0.013 | 0.036 | 0.36 | 0.029 | 0.97 | 1.05 |
| **Moana Beach, Waikiki** (Leeward Oahu) | 13.42 | 0.004 | 0.016 | 0.14 | 0.017 | 0.12 | 0.41 |

## 3.6.2 Is the Ocean Polluted near the Mouth of the Waiʻulaʻula Stream?

There are two important questions about water quality in Kawaihae Bay at Waiʻulaʻula:

(1) Is the water polluted with nutrients, sediment, and algae?
(2) How does water quality in Kawaihae Bay at Waiʻulaʻula compare to water quality in other Hawaiian shorelines?

Comparison of measurement against the water quality standards (Table 9) shows that the Bay has too much ammonia (concentrations are 2.8 more than what is allowed) and too much chlorophyll (concentrations are double what is allowed). The high chlorophyll levels indicate that there is too much algae. It is likely the high ammonia levels are contributing to high excess algae. Because ammonia is rapidly converted to nitrate in the presence of oxygen, it is likely that the source of the ammonia is nearby. The measured nitrate and total nitrogen concentrations are near the standard. Total phosphorus concentrations are slightly above the standard.

Water quality in Kawaihae Bay at Waiʻulaʻula is considerably better than in nearby Pelekane Bay (Table 9). The water quality in Pelekane Bay is poor: there are high levels of sediment, ammonia, nitrate, and chlorophyll. If Pelekane is excluded, then the water quality in Kawaihae Bay at Waiʻulaʻula is roughly the same or better than the comparison beaches shown in Table 9. Compared to the other beaches, Waiʻulaʻula has lower concentrations of total phosphorus and nitrate. Waiʻulaʻula's chlorophyll and ammonia concentrations are lower than some beaches and higher than others. For suspended sediment, Waiʻulaʻula's concentration is the same or better than that found at comparison beaches.

In summary, the waters of Kawaihae Bay at Waiʻulaʻula are impaired by excessive levels of ammonia and algae. Levels of other nutrients are near the standard or slightly above. The levels of nutrients and algae are comparable to —if not slightly better than —many other Hawaiian beaches. Notably, Pelekane Bay, which receives runoff from the watershed immediately north of the Waiʻulaʻula watershed, is strongly impaired by high levels of nutrients, sediment, and algae. It is important to prevent conditions in Waiʻulaʻula watershed from deteriorating to the level found in Pelekane watershed.

Marine water quality can deteriorate after watershed runoff events and after high surf events. To see if the runoff events were a factor at Kawaihae Bay (Waiʻulaʻula outlet), Kawaihae data (33 measurements made over 22 months) were compared with stream discharge in the watershed headwaters (Marine Dam) and with open ocean wave height (NOAA buoy 51003 at 19.087N, 160.66W). When streamflow increases at Marine dam, ocean TN and silica increase two days later. (Silica comes from the land, not the ocean). This suggests that watershed runoff is contributing nitrogen to the bay. Marine algae concentrations are *lower* when there is high surf or higher than usual streamflow. This could indicate that coastal waters are being diluted with either open ocean seawater or stream floodwaters.

## 3.7 Watershed Loads (total amount of pollutants)

"Loads" are the total amount of a pollutant that is exported from a watershed. Loads are usually measured in pounds (of Nitrogen, Phosphorus, or Sediment) per year. We want to know what the loads are now, what they will be in the future, and whether there is anything that can be done to reduce loads. Existing loads can be measured, although obtaining data is very expensive. Modeling can be used to estimate loads for locations where measurements are not available.  Modeling is also used to estimate future loads or reductions in loads resulting from remediation efforts.

Measuring loads requires simultaneous measurements of stream discharge and sediment/nutrient concentration.  Discharge and concentration are multiplied together to obtain loads or fluxes.  (Fluxes and loads are synonyms.)  The MKSWCD measured fluxes for several runoff events, but did not make the year-long measurements necessary to obtain the total load for an entire year.  Annual loads were, therefore, estimated using NOAA's N-SPECT model.

### 3.7.1 Load Measurements

Each autosampler collected discharge and water quality data for several runoff events.  By multiplying discharge and sediment/nutrient concentration together, it is possible to calculate the load (pounds of sediment, nitrogen, phosphorus) carried by the stream for a particular runoff event (Table 10).  The values in Table 10 represent all the pollutants carried by the stream (at each location) for a particular runoff event.  Not all storms were sampled, so we do not have annual loads (total for an entire year).  The discharge at the upper sampler was measured very accurately, but the discharge measurements at the other locations are approximate.  As a result, the load measurements are approximate for all but the upper site (Marine Dam).  Data from the Marine Dam site are reasonably representative of loads produced in the high-elevation forests.  Data from the Sandalwood site and the watershed outlet, however, represent a mix of land uses.

The load measurements, while valuable, are limited because they cover only some locations and some storms.  Because weather varies from one year to the next, several years of data would be needed to obtain a reliable estimate of the average annual load.  Because such data do not exist for the Waiʻulaʻula watershed, a model was used to estimate average annual loads and examine spatial variations over the watershed.  Collection of even one complete year of data would be very expensive and currently there are no immediately plans to do so.

### 3.7.2 Using the N-SPECT Model to Estimate Loads and Spatial Variability in Pollutants

The Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT model) estimates average annual pollutant loads as a function of climate, soil characteristics, topography, and landcover class.  (Landcover classes describe both vegetation and land use.)  One advantage of using a model is that it will provide explicit estimates of the contributions of each landcover class.  N-SPECT can also identify areas that are particularly susceptible to erosion or predict the change in loads resulting from land use changes.  The success of this approach depends on the model's assumptions about how runoff coefficients and nutrient concentrations vary among landcover classes.  The key issue is whether the relative differences between landcover classes reflect the relative differences in the actual watershed.

### Table 10: Measured Loads

Measurements of the amount of nutrients and sediment carried by the stream during a particular runoff event. Values represent how much was carried past each autosampler. The Marine Dam site is above Waimea Town near the lower edge of the forest. The Sandalwood site is immediately below Waimea Town. TN values in italics were estimated from sediment and TDN data.

| SITE | Runoff event | Sediment Tons | TDN lbs as N | TN lbs as N | $NO_3$+$NO_2$ lbs as N | $NH_4$ lbs as N | $PO_4$ lbs as P | TP lbs as P | Runoff acre-feet* |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| Marine Dam | 11/1/07 | 0.2 | 12.9 | 19.0 | 1.1 | 1.0 | 0.3 | 2.6 | 20 |
| Marine Dam | 11/6/07 | 0.5 | 12.3 | 22.5 | 0.6 | 0.8 | 0.3 | 3.2 | 20 |
| Marine Dam | 11/14/07 | 0.1 | 3.0 | 5.4 | 0.6 | 0.4 | 0.2 | 0.7 | 15 |
| Marine Dam | 12/3/07 | 0.4 | 17.6 | 27.7 | 1.4 | 1.6 | 0.4 | 2.3 | 34 |
| Marine Dam | 12/5/07 | 3.7 | 71.4 | 115.3 | *3.6* | 3.5 | 0.8 | 19.4 | 113 |
| Marine Dam | 12/16/07 | 7.5 | 68.6 | 172.6 | 7.4 | 10.5 | 2.0 | 55.6 | 169 |
| Marine Dam | 1/26/08 | 0.1 | 9.3 | 11.5 | 1.2 | 1.1 | 0.2 | 0.4 | 19 |
| **geometric mean** | | **0.5** | **16.8** | **28.3** | ***1.5*** | **0.4** | **0.4** | **3.4** | **36** |
| | | | | | | | | | |
| Sandalwood | 11/22/07 | 5.4 | 55.3 | 143.5 | 26.6 | 3.6 | 3.2 | 36.2 | 81 |
| Sandalwood | 12/6/07 | 6.8 | 102.1 | 199.3 | 26.6 | 5.4 | 4.3 | 51.1 | 135 |
| Sandalwood | 12/16/07 | 9.2 | 72.6 | 200.6 | 13.2 | 3.9 | 3.0 | 84.2 | 164 |
| Sandalwood | 1/26/08 | 0.1 | 7.3 | 9.3 | 2.2 | 1.1 | 0.3 | 0.6 | 12 |
| **geometric mean** | | **2.1** | **41.6** | **85.5** | **11.9** | **3.1** | **1.9** | **17.7** | **68** |
| | | | | | | | | | |
| Coastal outlet | 1/17/09 | 1.1 | 47.0 | 87.9 | 20.4 | 2.7 | 0.4 | 4.9 | 39 |
| Coastal outlet | 2/3/09 | 1.7 | 71.2 | 121.0 | 7.1 | 8.5 | 1.3 | 7.9 | 106 |
| **geometric mean** | | **1.4** | **57.9** | **103.1** | **12.0** | **0.5** | **0.0** | **6.2** | **64** |
| 34 | | | | | | | | | |
| Pelekane | 12/6/07 | **157** | **157** | **199** | **6147** | **79** | **22** | **5** | **204** |

* An acre-foot is a volume equal to one acre of land flooded to a depth of one foot.

N-SPECT, which was developed by NOAA, is a GIS-based watershed model. It uses the SCS Curve Number method to estimate runoff and the RUSLE method to estimate erosion export of sediment from the watershed. The watershed's export of total nitrogen and total phosphorus are estimated by multiplying predicted runoff by the average concentration of nitrogen and phosphorus in streamwater. At the time the modeling was done, the field measurements in the Wai'ula'ula watershed had not been collected. (Even if they were available, most of the data represent a mix of landcover classes, whereas we needed distinct values for each different landcover class.) Default pollutant coefficients (NT and TP concentrations in mg/L), which had been developed from a national database, were therefore used (Table 11). The Wai'ula'ula watershed was divided into 4 sub-basins, based on elevation and precipitation gradients, to allow for distribution of the raining days factor in the model (Figure 25). The Mauna Kea "leg" was excluded, for reasons described in Section 2.1.1. The modeling work was conducted by Ms. Katie Gaut as part of her Master's thesis (Gaut 2009).

**Table 11: Pollutant Coefficients (average concentrations in runoff)**

| | Total Phosphorus (mg/L) | Total Nitrogen (mg/L) | comment |
|---|---|---|---|
| Model's Default Values for various CCAP categories | | | |
| High Intensity Development | 0.47 | 2.22 | |
| Low Intensity Development | 0.18 | 1.77 | |
| Cultivated Land | 0.42 | 2.68 | |
| Grassland | 0.48 | 2.48 | |
| Evergreen Forest | 0.05 | 1.25 | |
| Scrub/ Shrub | 0.05 | 1.25 | |
| Bare Land | 0.12 | 0.97 | |
| Measurements (provided for comparison) | | | |
| Waimea urban runoff | 0.51 | 2.67 | arithmetic average of all measurements |
| Marine Dam (Forest) | 0.08 | 0.35 | volume-weighted average of 7 events |
| Sandalwood (below Waimea) | 0.16 | 0.52 | volume-weighted average of 4 events |
| Watershed outlet | 0.03 | 0.49 | volume-weighted average of 3 events |

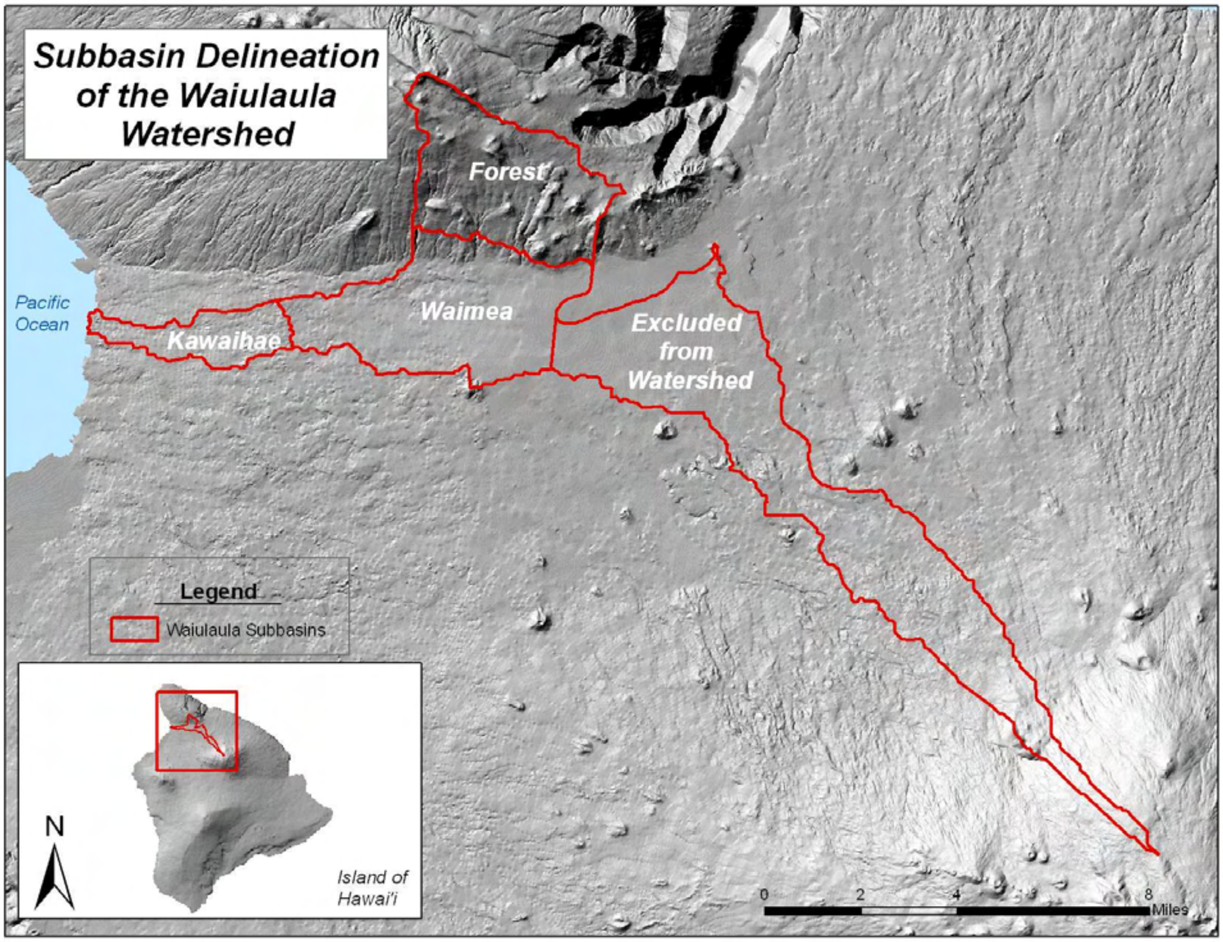



**Figure 25: Sub-basin Delineation of the Waiulaula Watershed for N-SPECT (from Gaut 2009)**

Gaut (2009) notes that the limited hydrologic and water quality data for the watershed "means that it is not possible to validate the model by statistically rigorous comparison with historic observations. She goes on to add "Nevertheless, model simulations that are based on reasonable assumptions, expert advice of local resource managers, and default parameter values may give results that are of sufficient quality for the purposes of section 319-related watershed management" (p.14).

Modeled runoff was similar to stream gage measurements in the watershed, as well as other watersheds within Hawaiʻi (Table 12). The best results were obtained when the model's "raining days" parameter was set to 0.50 inches. In the model, the forest sub-basin accounts for the majority of runoff.

**Table 12: Model Prediction of Pollutant Concentrations**

Measured values are volume-weighted averages from the autosampler sites. Modeled and measured values are not directly comparable because the former represents the annual average, whereas measurements reflect only four (Sandalwood), seven (Marine Dam), or three (outlet) storms.

| | Total Phosphorus concentration mg/L | Total Nitrogen concentration mg/L | TSS concentration mg/L |
|---|---|---|---|
| Marine Dam Measured Values | 0.08 | 0.35 | 23 |
| Marine Dam Modeled Values | 0.06 | 1.27 | 12 |
| Sandalwood Measured Values | 0.16 | 0.52 | 40 |
| Sandalwood Modeled Values | 0.34 | 2.01 | 42 |
| Watershed outlet measured values | 0.03 | 0.49 | 13 |
| Watershed outlet Modeled values | 0.16 | 1.56 | 14 |

Gaut (2009) calculated the relative contributions of major tributaries for total suspended solids, nitrogen, and phosphorus (See Figure 26 and Table 13). This information can help direct future monitoring efforts in the watershed so that ground-truthing can help confirm these results. She found:

> The largest contributors of runoff were Kohākōhau and Waikoloa streams. As these are the only two perennial streams in the watershed, the results are reasonable and expected. These two tributaries also are the primary contributors of nitrogen and total suspended solids to the watershed, with a combined input of 57% and 47%, respectively. Kohākōhau and Lanikepu Gulch were the primary and secondary tributary contributors of phosphorus, respectively. Lanikepu Gulch was found to deliver the majority of sediment. Mamaewe Gulch and Kohākōhau were the secondary tributaries for sediment delivery. (67%)

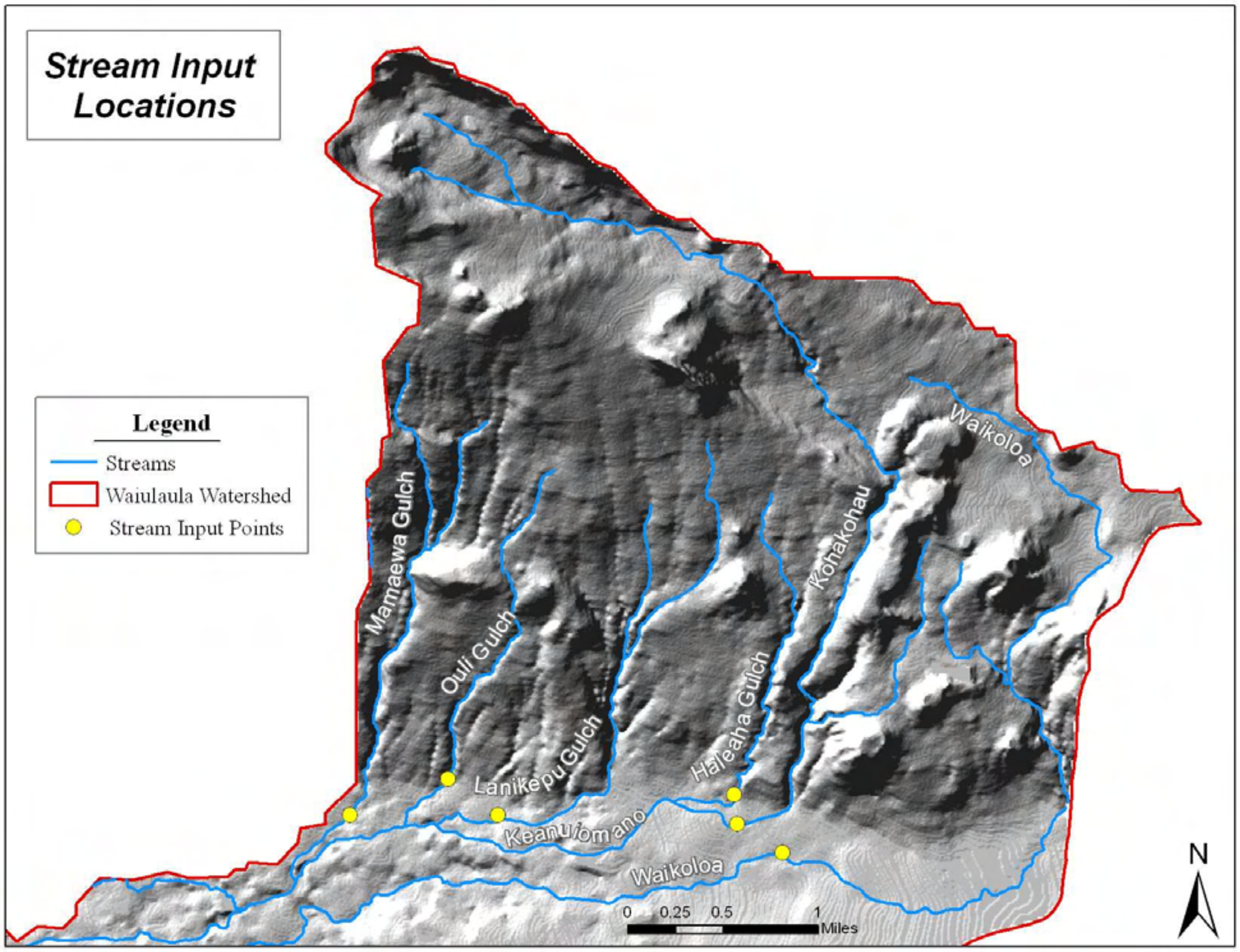



**Figure 26: Tributaries in the Wai'ula'ula Watershed Assessed for Runoff, Nutrient, and Sediment Contributions in Table 11 (Figure 19 in Gaut 2009)**

The model's estimate of sediment concentration (TSS) was about 20% higher than the measured concentration at the Marine Dam autosampler and more than double the measured concentration at the Sandalwood autosampler. Also, the model produced higher sediment loads than has been observed in other watersheds in Hawai'i. It is possible that NSPECT under-estimated the amount of sediment that is re-deposited a short distance from where it was eroded. Or, it is possible that some of the RUSLE/MUSLE coefficients are not appropriate to Hawai'i. On an average annual basis, the model predicts that the accumulated nitrogen load from the watershed is approximately 23,000 kg or 1.4 kg/acre/year, while the predicted accumulated phosphorus is 2,176 kg or 0.129 kg/acre/year (Gaut 2009). When compared to other watersheds in Hawai'i, N-SPECT produced reasonable estimates of nitrogen and phosphorus loads; however, the limited water quality data collected by autosamplers within the Wai'ula'ula watershed suggest these estimates may be high (Gaut 2009).

**Table 13: Relative contributions of major tributaries for pollutants displayed.**

Underlined and bold values represent the first and second largest contributor tributaries for that particular pollutant, respectively. (From Gaut 2009: Table 28)

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | **Mamaewa Gulch** | **Ouli Gulch** | **Lanikepu Gulch** | **Haleaha Gulch** | **Kohakohau** | **Waikoloa** |
| Accumulated Sediment | **25%** | 8% | <u>26%</u> | 10% | 24% | 7% |
| Accumulated Runoff | 11% | 4% | 15% | 7% | <u>39%</u> | **24%** |
| Accumulated Nitrogen | 13% | 5% | 17% | 7% | <u>36%</u> | **21%** |
| Accumulated Phosphorus | 19% | 8% | **21%** | 10% | <u>28%</u> | 14% |
| Accumulated TSS | 13% | 5% | 17% | 7% | <u>36%</u> | **21%** |

The model was also used to identify “critical” areas that produced disproportionately large amounts of sediment and nutrients (Figures 27, 28, and 29). The model predicts high sediment sources in the mid-west region of the forest sub-basin, as well as the lower reaches of the Waimea sub-basin. Gaut (2009) notes that “the top 1% of source areas are on steep grassy slopes. In the middle region of the watershed, however, the high sediment source areas appear to be associated with bare lands....” (p. 70). The model predicts that the lower watershed produces little sediment and nutrients. The reason for this is probably that there is little rainfall in the lower watershed.

If critical areas are identified, then selected BMPs can be evaluated with N-SPECT to assist in estimating potential load reductions from the implementation of these BMPs. Gaut (2009) examined several BMPs. She found that restoration of riparian areas did result in significant reductions in accumulated sediment and phosphorus (11% and 8%). Replanting of 50% of the bare land resulted in a 15% reduction of accumulated sediment. The modeling effort found little to no change in polluted runoff with the implementation of BMPs on agricultural (cultivated) lands. However, it may be that, given the small proportion of cultivated agricultural land in the watershed, the N-SPECT model operates at too large a scale (30x30 meter pixels) to accurately model these BMPs (Gaut 2009).

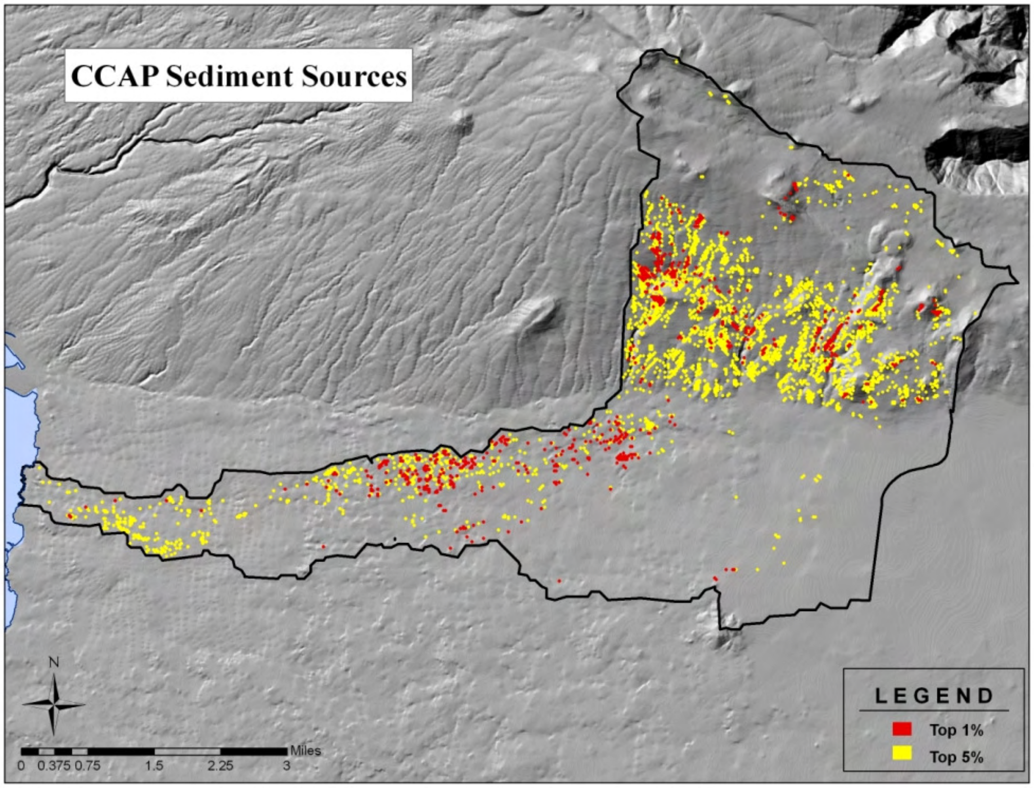



**Figure 27: Modeled Sediment Sources**

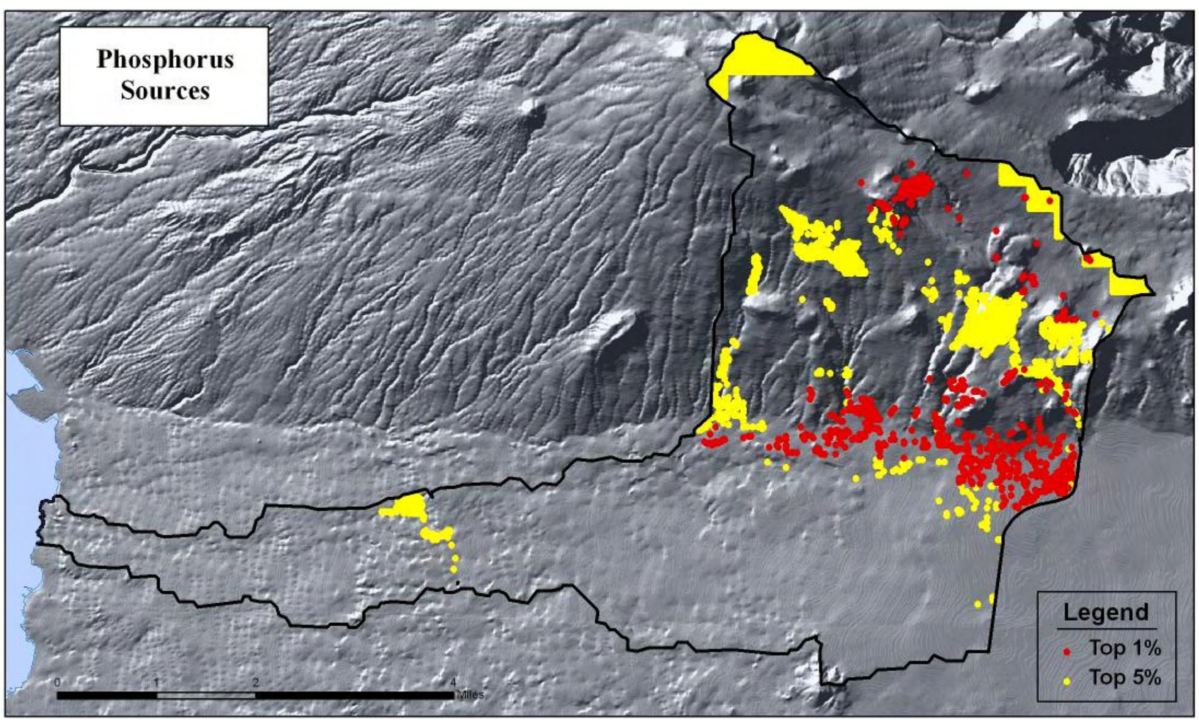



**Figure 28: Modeled Phosphorus Sources**

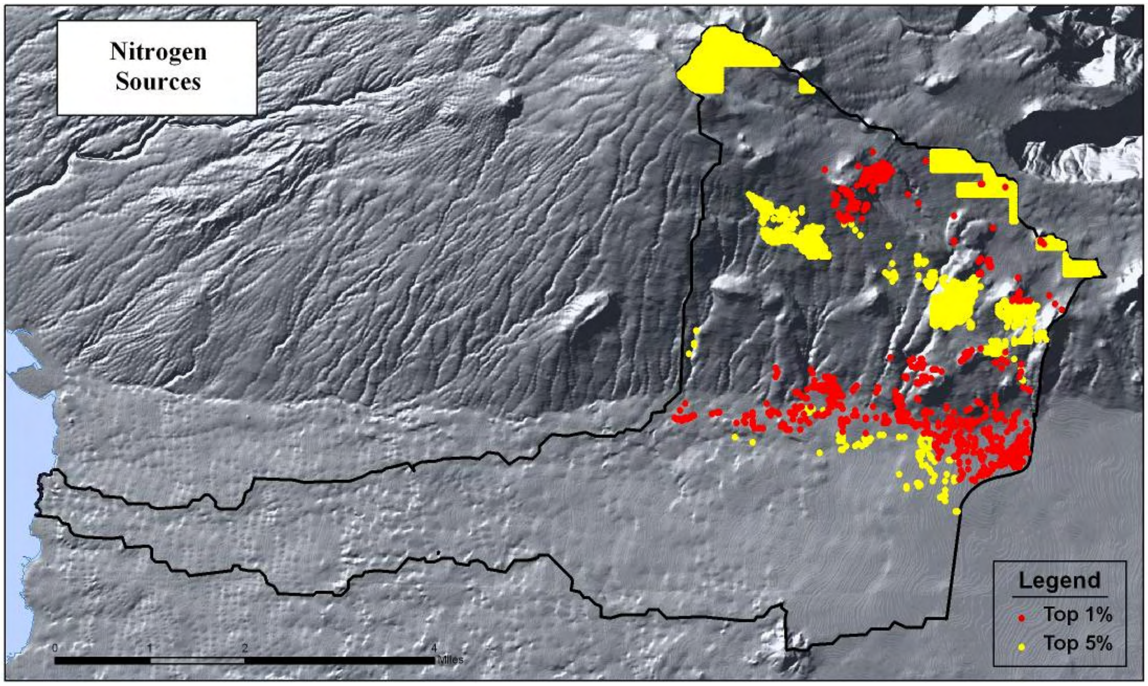



**Figure 29: Modeled Nitrogen Sources**

### 3.7.3 Using the N-SPECT Model to Estimate Future Loads

Gaut (2009) also ran a simulation of future conditions, using land use changes projected in Hawaiʻi County's General Plan LUPAG (Table 14). She found:

> Percent changes for the future scenario predict further increases in runoff, nitrogen and phosphorus. The phosphorus amounts are predicted to increase by over 20%. In addition, a large proportion of the increase in the amount of phosphorus is expected to occur at a close proximity to the coast. Much of the watershed that is currently classified as bare land is planned to be converted to urban expansion zones, which will cause the predicted overall accumulated sediment to decrease. (p. 79)

While the absolute quantitative output values may not be accurate, "they are indicative of the overall magnitude and patterns of sediment and nutrient delivery in the watershed" (Gaut 2009: 79).

**Table 14: Current and Future Load Estimates from the N-SPECT Model (based on Gaut 2009: Table 33)**

Exports are at the watershed mouth (where the stream enters the ocean).

| | Current Scenario | Future Scenario | % Change from Current |
|---|---|---|---|
| Total Watershed Runoff ($m^3$/yr) | 15,290,900 | 16,692,500 | 9% |
| Total Sediment Export (tons/yr) | 233,637 | 212,551 | -9% |
| Total Nitrogen Export (kg/yr) | 23,860 | 26,824 | 12% |
| Total Phosphorus Export (kg/yr) | 2,473 | 3,003 | 21% |

## 3.8 Toxics

University of Hawaiʻi graduate student James Tait conducted a study to see if trace elements in stream sediment reflect land use in the upstream watershed (Tait 2008). Four main classes of land use were evaluated as potential sources of pollution: Urban, Cultivated, Pasture / Rangeland, and Forest. The study looked at lead (Pb), zinc (Zn), copper (Cu), arsenic (As) and Vanadium (V).

Tait concluded:

> Both anthropogenic and natural factors were found to influence the composition of soils and streambed sediment. The composition of non-point pollutants often showed significant variability but some consistent trends were identified:
> .
> - Lead and zinc were enriched in surface soils that are near roadways.
> - Larger urban areas were associated with more lead and zinc in streambed sediment (downstream of the urban area). This was also true to a lesser extent for Copper.

The Tait study also looked at whether the isotopic composition of nitrate in stream waters could be used to identify the source of nitrate. These results were inconclusive, however.

## 3.9 Biological Data

Assessment of ecosystem health can be based either on water quality or on biological populations. A healthy ecosystem is diverse and contains native species.

DLNR's *Atlas of Hawaiian Watersheds and Their Aquatic Resources* (2008) compiles information from many years of surveys and publications on Hawaiian stream animals. The following data, taken from DLNR (2008), comes from biotic samples collected in 1968, 1990, 1992, 1994, 1999, 2000, and 2001 (Table 15). It includes data most recently collected by Bishop Museum's Hawaiʻi Biological Survey for DHHL's Lālāmilo Residential Project EIS. In addition, information from the recent stream survey undertaken by Englund (2010) is also included.

**Table 15: Distribution of Biotic Sampling**

The number of survey locations that were sampled in the various reach types.

| Survey type | Estuary | Lower | Middle | Upper | Headwaters |
|---|---|---|---|---|---|
| Damselfly Surveys | 0 | 0 | 1 | 0 | 1 |
| DAR Point Quadrat | 0 | 26 | 41 | 129 | 0 |
| HDFG | 0 | 0 | 0 | 0 | 1 |
| Microhabitat Survey | 0 | 0 | 0 | 24 | 0 |
| Published Reports | 1 | 1 | 1 | 2 | 1 |

Table 16 compiles the list of species found in different stream reaches within the Waiʻulaʻula watershed. The letter "P" indicates the presence of that species in that reach of stream. Data from DLNR (2008) is in regular font; data from Englund (2010) is in bold font. The reach classification system was developed by Parham and Lapp (2006). The reach types are based on elevation and the presence of different sized barriers (waterfalls) in the stream:

- Estuary: all stream segments between the coastline and 1 m. elevation.
- Lower Reach: stream segments between 1 and 20 m. elevation and below any barrier of approximately 10 m. high.
- Middle Reach: stream segments greater than 20 m. elevation or above the first 10 m. barrier and less than 200 m. elevation or below the first 20 m. high barrier.
- Upper Reach: stream segments greater than 200 m. elevation or above the first 20 m. barrier and less than 750 m. elevation.
- Headwaters: stream segments greater than 750 m. elevation.

**Table 16: Presence (P) of Species in Different Stream Reaches**

| Scientific Name (Common Name) | Status | Estuary | Lower | Middle | Upper | Head-waters |
|---|---|---|---|---|---|---|
| **Fish** | | | | | | |
| *Lentipes concolor* (ʻoʻopu hiʻukole) | Endemic | | | | P | **P** |
| *Sicyopterus stimpsoni* (ʻoʻopu nōpili) | Endemic | | P | P | P | |
| *Stenogobius Hawaiʻiensis* (ʻoʻopu naniha) | Endemic | **P** | | | | |
| *Eleotris sandwincensis* (ʻoʻopu ʻakupa) | Endemic | **P** | | | | |
| *Awaous guamensis* (ʻoʻopu nākea) | Indigenous | **P** | P | P/**P** | P | |
| *Mugil cephalus* (striped mullet) | | **P** | | | | |
| *Gambusia affinis* (mosquito fish) | Introduced | | P | P | P/**P** | |
| *Poecilia reticulate* (guppy) | Introduced | | P/**P** | **P** | P/**P** | |
| *Misgurnus anguillicaudatus* (dojo loach) | Introduced | | | P/**P** | P/**P** | |
| *Poeciliidae sp.* | Introduced | | P | P | P | |
| **Crustaceans** | | | | | | |
| *Macrobrachium grandimanus* (ʻŌpae ʻoehaʻa) | Indigenous | | P | **P** | | |
| *Macrobrachium Iar* (Tahitian prawn) | Introduced | | P | P/**P** | P/**P** | |
| *Procambarus clarki* (crayfish) | Introduced | | | | **P** | |
| *Hyallela azteca* | | | | | **P** | |
| *Metopograpsus sp.* (Purple climber crabs) | Indigenous | **P** | | | | |
| **Mollusks** | | | | | | |
| *Physa sp.* | Introduced | | **P** | **P** | **P** | |
| *Lymnaea sp.* | Indigenous | | | | | **P** |
| **Amphibians** | | | | | | |
| *Bufo marinus* (Cane toad) | Introduced | | P/**P** | P/**P** | P | |
| *Rana catesbeiana* (American bullfrog) | Introduced | | | | P/**P** | **P** |
| *Rana rugosa* (wrinkled frog) | Introduced | | **P** | **P** | **P** | |
| *Ranidae sp.* (bullfrog) | Introduced | | P | | | |
| **Aquatic Insects** | | | | | | |
| *Anax junius* (common green darner) | Indigenous | **P** | **P** | **P** | P/**P** | |
| *Anax strenuous* (giant Hawaiʻian dragonfly) | Endemic | | | | P/**P** | **P** |

| Scientific Name (Common Name) | Status | Estuary | Lower | Middle | Upper | Head-waters |
|---|---|---|---|---|---|---|
| *Crocothemis servilia* (scarlet skimmer) | Introduced | | | **P** | P/**P** | |
| *Orthemis ferruginea* (roseate skimmer) | Introduced | | | **P** | P/**P** | |
| *Pantala flavescens* (wandering glider) | Indigenous | | **P** | **P** | P/**P** | |
| *Tramea lacerate* (black saddlebags) | | | | **P** | **P** | |
| *Megalagrion caliphya* | Endemic | | | | | **P** |
| *Enallagma civile* (familiar bluet damselfly) | Introduced | | | P | P/**P** | |
| *Ischnura ramburii* (Rambur's forktail) | Introduced | **P** | **P** | P/**P** | **P** | |
| *Chironomus Hawaiʻiensis* (Hawaiian midge) | Endemic | | | | P | |
| *Megalagrion sp.* (dragonfly) | Endemic | | | P | P | |
| *Orthocladius grimshawi* | Endemic | | | | P | |
| *Ischnura posita* | Introduced | | | | | P/**P** |
| *Rhantus gutticollis* | Introduced | | | | P | |
| **Diptera (Flies, gnats)** | | | | | | |
| *Chironomus sp.* | Endemic | | | **P** | | **P** |
| *Procanace sp.* | Endemic | | | | | **P** |
| *Forcipomyia hardyi* | Endemic | | | | | **P** |
| *Cricotopus bicinctus* | Introduced | | | | P | **P** |
| *Dolichopus exsul* | Introduced | | | | | **P** |
| *Dolichopodidae sp. 1* | Endemic | | | | | **P** |
| *Scatella sp.* | Endemic | | | | P | **P** |
| *Scatella clavipes* | Endemic | | | | P | |
| **Heteroptera** | | | | | | |
| *Saldula exulans* | Endemic | | | | | **P** |
| *Microvelia vagans* | Endemic | | | | | **P** |
| **Trichoptera** | | | | | | |
| *Cheumatopsyche analis* | Introduced | | | | | **P** |
| *Oxyethira maya* | Introduced | | | | **P** | **P** |
| **Bryozoans** | | | | | | |
| *Plumatella repens* | Introduced | | | P | | |

As noted in Section 2.1.10, the biodiversity of native species found in the Waiʻulaʻula watershed is high. This indicates that, from a biological resources standpoint, the stream quality is very high, particularly in the upper reaches.

## 3.10 Summary

### 3.10.1 Pollutants of greatest concern and their spatial variability

Water quality data were collected for the purpose of determining which nonpoint pollutants are of the greatest concern in the watershed and in the marine receiving waters. Marine waters just offshore of the watershed have excessive levels of algae and ammonia. Ammonia is a form of nitrogen that is especially harmful to marine life. For streams, the parameter of greatest concern is total nitrogen (TN), followed by total phosphorus (TP). Suspended sediment and nitrate are parameters of possible concern. Stream water quality was measured in three locations. The highest levels of nutrients and sediment were found at the downstream edge of Waimea Town, and the lowest levels were found where Waikoloa stream exits the forest. Intermediate levels were found at the watershed outlet (where the stream enters the ocean).

There are high levels of pollutants in runoff from high-use paved areas in urban Waimea. This urban runoff has particularly high values of TSS, TN, and TP. The headwaters of the watershed contain pristine forests. Runoff originating in the forest contains sediment and nutrients, but, for the most part, the concentrations are not particularly high. The forest runoff does, however, have slightly elevated TN concentrations, and, occasionally, TP concentrations are elevated.

### 3.10.2 Information Gaps

A few of the following data gaps are addressed in the monitoring plan (Chapter 6).

- Monitoring has been conducted on only one of the two major tributaries of the Waiʻulaʻula Stream. We do not have data for Keanuʻiʻomanō stream, so it is unknown if different sections of the high elevation forest generates runoff with different chemical characteristics. It is possible that there are differences based on vegetation type (nitrogen fixing or not) or distribution of oxygen-poor bogs.

- The middle reaches of the stream are intermittent, and there are periods when these reaches contain stagnant isolated pools. Although these pools are small, they are quite important to aquatic species. It is likely that the water quality in these pools is poor, but we do not have any measurements of water quality. Nor do we know the extent to which these pools are adversely affected by upstream diversions (both legal and illegal).

- Interpretation of the nitrogen data is complicated by the fact that we know little about the nitrogen transformations (one type changing into another) (cycling) occurring in Waiʻulaʻula Bay.

- We do not know if the stream water is N-limited or P-limited. Nor do we know if Waiʻulaʻula Bay is N-limited or P-limited.

- We are unsure if the lower Waiʻulaʻula watershed is capable of occasionally generating the kind of sediment-rich runoff that has been observed in the Pelekane Bay watershed immediately to the north. Based on one event measured at the outlet of Pelekane watershed, the concentration of sediment in Pelekane storm runoff is 150 times greater than what is allowed. The total nitrogen concentration was 240 times greater than what is allowed. The lower elevation regions of the Pelekane and Waiʻulaʻula watersheds are similar in climate and land use, so it is difficult to dismiss the possibility that, given the right storm, the lower portion of the Waiʻulaʻula watershed is capable of generating runoff with very high concentrations of sediment and nitrogen. On the other hand, the lower Pelekane watershed is steeper than the lower Waiʻulaʻula watershed and has older soils. Moreover, the comparison between the two watersheds is based on only one event for Pelekane and three events for Waiʻulaʻula. The Pelekane samples were collected on a day that we did not collect data at the outlet of the Waiʻulaʻula watershed.

- Sections of the Waiʻulaʻula Stream and its tributaries are losing streams, meaning that water leaks through the streambed. Infiltrating water likely goes into groundwater, although it is possible that some of it is taken up by streamside vegetation. Thus, the water that leaks through the streambed could eventually flow to the ocean. Notably, most of the lower reaches are losing. Also, it is likely that the stream is a losing one (at least some of the time) between the Sandalwood autosampler and the Marine Dam autosampler. This raises the question as to how much of the nonpoint pollutants generated in the upper and middle reaches of the watershed are delivered to the ocean. We do not have data on the amount of losses, however, nor on which reaches are gaining reaches.

- The modeling results suggest that large amounts of sediment are being eroded from certain sections of the middle watershed that have an unfavorable combination of intense rain and erodible soil. Ground-truthing is recommended to verify this result.

# Chapter 4: Threats to the Water Quality of the Watershed

This section describes the threats to the water quality of Waiʻulaʻula watershed. It responds to element (a) of EPA's 9 key elements for watershed-based plans that are critical for achieving improvements in water quality (see Appendix B). At this time, there are insufficient data to conclusively prioritize threats by load contribution or impacts to resources.

The focus of this management plan is on preventing further degradation of water quality. Possible pollutant sources and threats to the watershed are described below. Based on these threats, the management plan establishes goals and objectives for maintaining and restoring water quality.

## 4.1 Nonpoint Sources of Pollution

Nonpoint source pollution (or polluted runoff) is pollution that cannot be traced to a single source but, rather, comes from many diffuse sources. It generally results from precipitation, land runoff, infiltration, drainage, seepage, hydrologic modification or atmospheric deposition. As runoff from rainfall moves across the landscape, it picks up pollutants from human activities, ultimately depositing them in surface waters. Pollutants can also seep into the ground and affect groundwater, as well as surface water with connections to groundwater.

### 4.1.1 Agriculture

Agricultural activities, if not properly managed, can contribute polluted runoff in the forms of sediment, nutrients, pesticides and animal waste. Agricultural activities can also directly impact the habitat of aquatic species through physical disturbances caused by livestock or equipment. Agriculture is a significant land use in the Waiʻulaʻula watershed, with over 8,000 acres dedicated to crops and livestock grazing.

Good soil is essential to conventional farming. Farmers are generally motivated to prevent soil runoff and keep the soil on the land where it benefits food production. However, without proper management, there is always the potential for soil erosion into streams during storm events or from excessive irrigation after fields have been tilled and before there is sufficient vegetative cover to prevent runoff.

Sediment is a result of soil erosion. Soil erosion can be characterized as the transport of particles that are detached by rainfall, flowing water or wind. Eroded soil is either redeposited on the same field or transported from the field in runoff. The types of erosion associated with agriculture are typically sheet and rill erosion, and gully erosion. Sediments transported from the field into waterbodies often have other pollutants attached to the soil particles, such as nutrients and chemicals (herbicides, pesticides, etc.). Suspended sediments in stream and coastal waters reduce the amount of sunlight available to aquatic plants, cover fish spawning areas and food supplies, smother coral reefs, adversely affect the filtering capacity of filter feeders, and clog and harm the gills of fish.

Nitrogen (N) and phosphorus (P) are the two major nutrients from agricultural activities that can degrade water quality. Nutrients are applied to agricultural lands in several different forms and come from a variety of sources, including commercial fertilizers, manure, and irrigation water. While all plants require nutrients for growth, excessive nutrient application can cause runoff into streams and the ocean, disrupting ecosystems by causing blooms of aquatic and marine plants such as algae. In addition, over-application of nutrients costs the farmer unnecessary expense.

When excessive nutrients are introduced into a stream or ocean, aquatic plant growth may increase dramatically, a process called eutrophication. This adds more organic material to the system, which eventually dies and decays. The decaying organic matter can produce odors and deplete the oxygen supply required by aquatic organisms. Eutrophication also increases turbidity and is harmful to coral reefs.

The term pesticide includes any substance or mixture of substances used to prevent, destroy, repel, or mitigate any pest or intended for use as a plant regulator, defoliant, or desiccant. Pesticides are generally applied to crops to kill insects, molds, mildew, fungus, and weedy plants that are detrimental to the successful growth of the food crop. Pesticides can harm the environment by eliminating or reducing populations of desirable organisms and riparian or aquatic plants. Some chemicals resist degradation and can persist in soils and aquatic environments. Pesticides are normally transported into surface water either through direct application or attached to sediment in runoff.

Animal waste from agricultural activities in the Waiʻulaʻula watershed is comprised mostly of the fecal and urinary wastes of cattle. Not only is manure high in nutrients that can lead to eutrophication, but it can also contain bacteria, viruses, and pathogens. Cattle are currently allowed to graze adjacent to streams and access the streams for water. This facilitates the introduction of pollutants into the waterbodies of the watershed. Livestock grazing near and in the streams can also destabilize streambanks and reduce streambank vegetation.

The Mauna Kea Soil and Water Conservation District (MKSWCD) normally works with individual agricultural landowners to develop conservation plans for approval by the district. A conservation plan is a customized document that outlines the use of conservation practices to maintain or improve the natural resources that support productive and profitable agricultural operations. An approved conservation plan enables the landowner to be exempted from the county grading ordinances for any earthmoving activities. NRCS usually assists in developing conservation plans to treat existing and potential resource problems and has funding available for eligible participants to assist with the installation of best management practices, under the Federal Farm Bill. Every farm or ranch has its own unique resource problems or concerns. Conservation planning is a voluntary way for operators to meet land management goals, with planning assistance from NRCS and the local conservation district to help identify options that provide the greatest conservation benefit while meeting production goals.

Of the 640 acres currently used for farming, only 94 acres (or 15%) are farmed under conservation plans developed by NRCS and approved by the MKSWCD. While those farms with conservation plans are probably implementing appropriate best management practices to control erosion, properly manage nutrient and pesticide applications, and apply irrigation water, there are many others who may not be. This objective addresses the CNPCP management measures for agricultural erosion and sediment control, nutrient management, pesticide management, and irrigation water management.

As noted earlier, a high percentage of land in the watershed - both prime kikuyu land and marginal land - is used for grazing (about 8,000 acres). While the primary grazers, Parker Ranch and FR Cattle Co., have conservation plans with the Mauna Kea Soil and Water Conservation District, improvements can still be made. Infrastructure is limited, with more fencing to reduce paddock size and watering facilities needed. In some areas, cattle are accessing streams for water because there are no other sources of water available, causing streambank erosion, and adding nutrients and pathogens to the stream system.

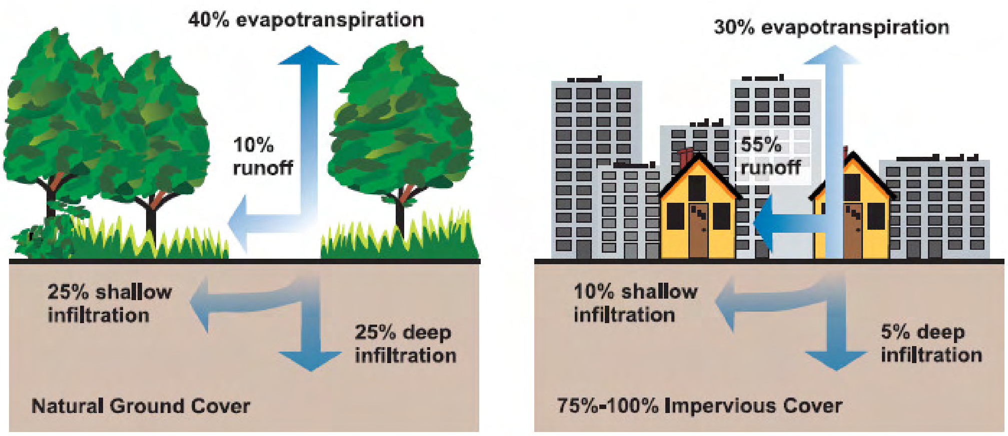
A considerable amount of land currently being grazed in the watershed is considered marginal lands. With sufficient rainfall, these lands support cattle production. During the drought conditions experienced during most of the past decade, grazing in these areas has been seasonal at best. However, the grazing of these lands can be considered a public benefit, protecting the numerous residential communities adjacent to these marginal lands. Without periodic grazing, the resulting tall, dry grasses would present a significant fire hazard.

The Conservation Reserve Enhancement Program (CREP) is a joint federal-state program that was recently started in Hawaiʻi to help restore degraded agricultural lands and reduce polluted runoff from these lands. It provides incentives to farmers and ranchers to remove degraded cropland and marginal pastureland from agricultural production and convert the land to native grasses, trees, and other vegetation.

### 4.1.2 Urban/Suburban Runoff

Urban development can have a negative impact on the hydrology and water quality of a watershed. Impervious surface area is often associated with polluted runoff. The “hardening” of the landscape that comes with urbanization increases runoff volumes and pollutant loadings. Impervious surfaces, such as rooftops, roads, parking lots, and sidewalks, decrease the infiltration capacity of the ground and result in greater runoff volumes that can exacerbate flooding problems. Urban development also causes an increase in pollutants, such as sediments, nutrients, pathogens, hydrocarbons, heavy metals, and toxins.

Scientists use percent imperviousness to describe how much of a given area is covered by hard surfaces. As the amount of impervious cover increases, the amount of runoff generated also increases, making it difficult for the water to seep into the soil because it is flowing so quickly. This visual, developed by EPA, shows the relationship between impervious cover and surface runoff. As little as 10% impervious cover in a watershed can result in stream degradation (EPA 2003).




According to NOAA's C-CAP Land Cover map, the high-intensity and low-intensity developed (urban) areas within the watershed are concentrated along the streams. While urban areas occupy relatively small areas of the Wai'ula'ula watershed (2%), their pollutant contributions can be significant. Measured water quality below Waimea town is significantly worse than upstream. Comparing water quality below Waimea to water quality above town, ammonia concentrations doubled, total phosphorus concentrations (TP) more than doubled, and nitrate concentrations quadrupled. Urban development within the watershed increased significantly over the past 30 years and is projected to continue to increase. The lower watershed is slated for urban expansion (Hawai'i County 2005), and additional urban growth is projected in Waimea town and along Waikoloa and Keanu'i'omanō streams.

Stormwater picks up nutrients, sediment, and chemical contaminants as it flows across yards, parking lots, construction sites, and parks. Roofs and driveways generate additional stormwater runoff that must be managed. Development activities like clearing vegetation, grading, removing or compacting soil, and adding impervious surfaces also increase stormwater and polluted runoff.

Fifty-five to seventy percent of impervious surfaces in an urban area are transportation associated (Chesapeake Bay Program 2008). Runoff from roadways and parking lots can have a particularly adverse effect on water quality if no measures are taken to remove contaminants before the runoff reaches the receiving water. Oil and grease are leaked onto road surfaces from car and truck engines, spilled at fueling stations, and discarded directly into storm drains instead of being taken to recycling stations. Heavy metals come from car and truck exhaust, worn tires and engine parts, brake linings, weathered paint, and rust. Rain water picks up these pollutants and carries them to roadsides or into storm drains.

In urban areas of the Waiʻulaʻula watershed, Hawaiʻi County has the lead in the control of erosion during site development, and ensuring proper site planning and stormwater management to protect sensitive natural features, through its ordinances and rules related to zoning, subdivisions, drainage, and erosion and sediment control. The State Department of Health also regulates stormwater runoff through its NPDES permit process. The Hawaiʻi Department of Transportation requires best management practices during construction of State roads, highways, and bridges. The Hawaiʻi CZM Program funded the production of a Low Impact Development (LID) manual for Hawaiʻi (Horsley Witten Group 2006), which describes stormwater and wastewater management techniques for urban and suburban areas that reduces impacts on sensitive water resources.

Many roads within the Waiʻulaʻula watershed are fitted with curb and gutter catch basins to convey stormwater away from roads. This stormwater is then discharged into dry wells or directly into streams, affecting either groundwater or surface water. On other roads, stormwater is conveyed to grassy shoulders on either side of the road, where it ponds until it is either absorbed or runs off. All the bridges in the watershed have scuppers that discharge stormwater directly into the streams below.

Hawaiʻi County has historically relied on deep (+20 feet) 5-feet diameter drainage injection wells (or "dry wells") as the primary means of capturing and disposing of urban stormwater runoff, because Hawaiʻi Island's geology allows for good lateral and downward percolation. The county allows a maximum disposal rate of 6 cubic-feet per second (cfs) of water per dry well (Kuba 2005). Many new and existing developments within the Waimea area employ dry wells to trap runoff from roadways and parking areas, notably the Parker Ranch shopping center, Sandalwood residential area, Parker Ranch's Lualaʻi development, and DHHL's new Lālāmilo housing development.

The U.S. Geological Survey in cooperation with Hawaiʻi County Department of Public Works assessed the potential for roadside dry wells to affect water quality (Izuka *et al.* 2010). Using the presence or absence of urbanization in the drainage area, distance between the bottom of the dry well and the water table, and the proximity to receiving waters, USGS identified wells that have the greatest potential to affect the water quality of receiving waters at the coast and in drinking-water wells. Effects to surface water were not considered. Water quality sampling of water entering the dry wells has not been undertaken on a large scale. Sampling of runoff into dry wells in Waimea show significant pollutant loads. Based on a limited amount of data, it appears likely that runoff from high-use paved areas exceeds water quality criteria for sediment (by a factor of five), total phosphorus (by a factor of four), total nitrogen (by a factor of three) and nitrate (measured values are only slightly greater than the standard).

According to Kuba (2005), all dry wells operate functionally “as both a sediment trap and a storm water disposal system.” The County Department of Public Works has a dry well cleaning program for its transportation-related dry wells to removed accumulated sediment in its more than 1,000 permitted dry wells island-wide, in order to maintain the capacity of these dry wells. It is less clear how frequently private dry wells are maintained.

**Pipe Discharging into Waikoloa Stream**

There is one large pipe discharging urban stormwater runoff directly into Waikoloa Stream. This concrete pipe is located behind the Waimea Community Education building on Māmalohoa Highway and discharges untreated runoff from storm drains along Māmalohoa Highway. PVC pipes discharge roof runoff from the KTA shopping center directly into Waikoloa stream. Within DHHL’s Lālāmilo development, it appears that runoff from the subdivision’s yards is being channeled down steep, rock lined slopes into Lanikepu and Keanuʻiʻomanō streams.

## 4.1.3 Wastewater Disposal Systems

Sewage contains pathogens, high levels of nutrients and oxygen-consuming organic matter. Standard sewage treatment (primary plus secondary) kills pathogens, removes solids, and removes some of the nutrients from the wastewater. Typically, a significant amount of nutrients (more than half of what was originally in the sewage) is not removed. Septic systems tanks are somewhat more effective than secondary treatment at removing nitrogen, but cesspools are less effective.

Sewer systems within the Waiʻulaʻula watershed are limited to sections of Waimea town and the Mauna Kea Beach Resort properties. Everyone else is using an onsite disposal system (OSDS), either a cesspool or septic system, which are effective over the long-term only if properly operated and maintained. When system failure occurs, untreated wastewater and sewage can be introduced into groundwater or nearby streams and waterbodies, introducing pathogens and causing eutrophication.

Hawaii has made progress in eliminating new individual cesspools[7]. Efforts to ban the use of new cesspools statewide have been made through revision to Chapter 11-62, HAR. The rule either bans or severely restricts the use of cesspools throughout the state. On Hawaiʻi Island, new cesspools for individual homes only are allowed in certain areas. These areas are designated in Critical Wastewater Disposal Area maps. The maps are based upon development density, groundwater development, potential contamination of coastal waters and the use of OSDS. In the Waiʻulaʻula watershed, cesspools are allowed in most areas on parcels of greater than 5 acres in size.

Although the current rule still allows some new cesspools in limited areas, there are a number of items that either prohibit new cesspools or require that existing cesspools be upgraded. These are described in Section 2.2.9.3.

Houses in the Waimea area built before 1991 will likely have cesspools, unless they were required to convert to a septic system because of problems with the existing cesspool or if significant changes were made to the structure. Houses built more recently, especially if part of a subdivision, will likely have septic systems. The type of wastewater system by TMK has not yet been mapped for the watershed, because at this time these data are not available in an electronic format. This information would help identify potential sources of nutrients within the watershed, and, then, more detailed water quality assessments can be undertaken to determine whether these systems, particularly the older cesspools, in neighborhoods adjacent to the streams are having a detrimental effect on surface water quality.

**Pumping Septic Tank**

[7] The U.S. Environmental Protection Agency (EPA) promulgated Underground Injection Control (UIC) regulations on December 7, 1999, which prohibited the construction of new large capacity cesspools (LCCs) nationwide, effective April 5, 2000. Existing large capacity cesspools were required to be replaced by an alternative wastewater system and closed by April 5, 2005. Numerous large capacity or "gang" cesspools in Waimea were converted to alternative systems as a result.

Parker Ranch owns and operates the Waimea Treatment Company, the only wastewater treatment plant in the Waimea area. The current treatment capacity is 0.1 MGD (100,000 gallons per day). Currently inflow is 65% of its capacity. Wastewater is treated to R-3 quality, which, according to DOH, is undisinfected water that has received primary and secondary treatment. Treated effluent is disbursed through a 40-acre sprinkler system that is located approximately 300 yards from the treatment plant on Parker Ranch land. The treatment plant currently handles sewage from areas of downtown Waimea, including the KTA shopping center, Parker Ranch shopping center, Ace hardware store, North Hawaiʻi Community Hospital, Kamuela senior housing project, Kahilu Theatre, HoloHolo Ku residential development, and Lualaʻi subdivision.

Mauna Kea Beach Resort also operates a wastewater treatment plant which serves all the resort-associated developments in the coastal part of the watershed, including Kumulani, Moani, Apa Apaʻa, Waiʻulaʻula, Kaunaoa, High Bluffs, Bluffs, and Hapuna and Mauna Kea Beach resorts. The plant's maximum capacity is 600,000 gallons per day (gpd), though current inflow ranges between 130,000 and 300,000 gpd. The wastewater is treated to R-1 standards, which is the highest level of treatment in Hawaiʻi. This means the wastewater goes through secondary treatment (activated sludge), tertiary treatment (filtration), and ultraviolet disinfection. The treated wastewater is then blended with brackish well water and used to irrigate the golf course.

### 4.1.4 Streambank Erosion

Hawaiʻi's streams are subject to wide fluctuations in both flow depth and velocity because of their flashy nature. As flow depths and velocities increase, the force of water flowing against the streambank removes particles from the banks. Over time, the erosion can cause the streambank to slump and fall into the stream channel. Runoff from adjacent land that enters a stream by flowing over the streambanks can also erode soil from streambanks, particularly if the banks are already unstable because of an absence of vegetation or roots holding soil in place. Streambanks can also be destabilized by hoof action, when cattle access the streams for water. Fallen trees or other debris in the stream channel can contribute to streambank erosion, as the flowing water finds other ways around the impediments in the stream channel.

Riparian buffers can help stabilize eroding streambanks. They can also help improve the quality of water resources by removing or ameliorating the effects of pollutants in runoff. A riparian buffer is defined as:

> an area of trees and other vegetation located in areas adjoining and upgradient from surface water bodies and designed to intercept surface runoff, wastewater, subsurface flow, and deeper groundwater flows from upland sources for the purpose of removing or buffering the effects of associated nutrients, sediment, organic matter, pesticides, or other pollutants prior to entry into surface waters and groundwater recharge areas. (Welsch 2007)

There are a number of streambanks within the Waiʻulaʻula that are experiencing erosion. The most significant are along Waikoloa stream within Waimea town and along Keanuʻiʻomanō stream from Waiʻaka bridge to Kamuela Plantations. A detailed survey of all streambanks is needed to discover the extent of the problem.

**Streambank erosion on Waikoloa Stream**

In 2004, NRCS prepared an *Engineering Report for the Waimea Nature (Ulu La`au) Park* (NRCS 2004), in which it conducted hydrologic and hydraulic analyses and developed alternatives for enhancing stream channel and bank stability and reducing flood-related damage to the park. The document outlines potential streambank treatments for several specific problem areas within the park.

Just upstream and downstream from the Waimea Nature Park, several areas have been identified where streambank stabilization is needed in association with the proposed Waimea Trails and Greenways path. In addition, the county has identified two stream crossings for the trail that will require streambank stabilization at the ends of the headwalls and culverts.

The streambanks behind and downstream of KTA shopping center are also experiencing erosion. This is the area where the stream jumped its banks during the 2004 flood event. A riparian buffer along this stream segment would help stabilize the streambank in a highly visible location in the middle of Waimea town.

### 4.1.5 Feral Ungulates

Wild pigs and goats can contribute to polluted runoff in the Waiʻulaʻula watershed. Feral pigs (*Sus scrofa*) create soil disturbances, accelerating degradation, erosion, landslides, and sedimentation. They destroy native habitat, spread seeds of weedy plants and eat native plants. They also serve as carriers and vectors of parasites and diseases, such as Leptospirosis, found in stream waters on Kohala Mountain. Feral pigs reduce and change the understory vegetation, affecting the watershed hydrology. The management of feral pigs in the forest reserve and NAR is addressed in KWP (2007) and will not be addressed under this plan.

The population of wild goats (*Ovis aries*) in West Hawaiʻi has increased dramatically over the past decade. Goats are extremely destructive herbivores that will eat nearly any type of available vegetation. These browsing ungulates are having a significant impact on the groundcover in the lower watershed. There is currently no management of these animals, and they roam freely in the watershed, moving in response to available vegetation and water sources. Goat-proof fencing will be critical to the success of any revegetation or groundcover management project proposed in the watershed.

### 4.1.6 Invasive Plants

There are numerous invasive plants that are well-established in the Waiʻulaʻula watershed. These plants in the forested upper watershed can out-compete native plants for nutrients or water and quickly alter a native ecosystem by changing the vegetation. The diversity of plants and physical structure of the forest is lost when invasive plants form homogenized plant communities. According to KWP (2007), "Many invasive plant root structures do not hold the soil well when the plants form monotypic stands, which can accelerate geologic processes like erosion.... This in turn accelerates geologic erosion and decreases water quality, resulting in reef sedimentation" (p. 54).

In the lower, more arid parts of the watershed, fountain grass (*Pennisetum setaceum*) has become a problematic plant. It poses a major fire threat and has been designated one of Hawaiʻi's most invasive horticultural plants by DLNR. Fountain grass is considered fire-promoting, because dry fountain grass is an excellent fuel for brush fires. It is also considered fire-adapted because it can survive wildfires, where native plants often cannot. Wildfires strip the land of vegetation and render the thin soil susceptible to erosion through runoff, leading to sedimentation of streams and nearshore waters.

### 4.1.7 Atmospheric Sources of Nitrogen

Nitrogen is present in the atmosphere as $N_2$ gas (comprising about 80% of the atmosphere), other types of nitrogen-containing gases that occur in trace amounts, tiny liquid droplets containing dissolved nitrogen, and in the form of dust that includes nitrogen compounds. Rain contains nitrogen in the form of nitrate. Part of a watershed's nitrogen input is from rain, or from so-called "dry deposition" of nitrogen-containing dust. A variety of natural (lightning) and man-made (combustion) processes contribute to atmospheric deposition of nitrogen. The extreme temperatures on the surface of a lava flow facilitate chemical processes that change $N_2$ gas to nitrate-rich cloud droplets (Huebert *et al.* 1999). The volcanic nitrate has been shown to be biologically-significant at certain locations near Kilauea Volcano, but the significance in the Waiʻulaʻula watershed is unknown. A new eruption of Mauna Loa could increase the delivery of atmospheric nitrogen to the watershed.

Another way that nitrogen can be transferred to watersheds is when plants (actually the bacteria on their roots) "fix" atmospheric nitrogen (turn it from a gas to forms that plants can use). The distribution of nitrogen-fixing plants, particularly crops, is therefore important. In some watersheds, it is not uncommon for atmospheric deposition to account for one-third of the nitrogen inputs and biological fixation to account for another one-third. The density and distribution of nitrogen-fixing plants within the watershed is therefore significant. Elsewhere on Hawaiʻi Island, the spread of the nitrogen-fixing Albizia tree is affecting watershed nitrogen budgets (Atwood *et al.* 2010).

It is estimated that human activities have doubled the amount of atmospheric nitrogen that is delivered to tropical watersheds (relative to background).

## 4.2 Wildfire

Wildfire is a significant threat in the Waiʻulaʻula watershed. In the last decade, some part of the watershed has burned every couple of years on average, due to the recurring fire cycle and unmanaged grass fuels. Wildfires strip the land of vegetation and render the thin soil susceptible to erosion through runoff, leading to sedimentation of streams and nearshore waters. It was estimated, using the modeling tool called the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT), that if 1,350 acres in the lower watershed burned, it could increase the load of total suspended sediments to the streams and coastal waters by 290%.

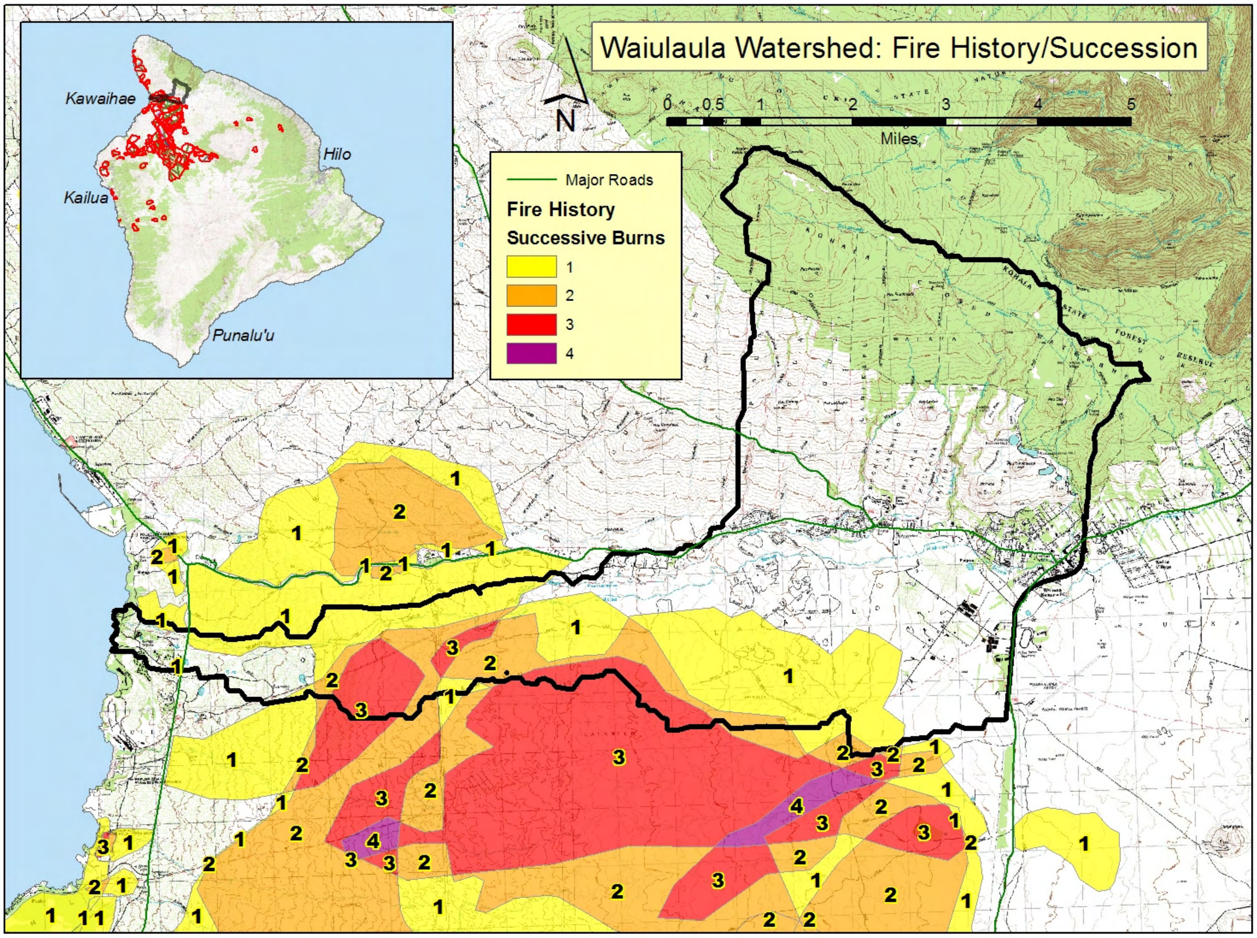
The changing composition of vegetation in the watershed has contributed to an increased fire hazard. Alien grasses, such as fountain grass (*Pennisetum setaceum*), now dominate much of the lower watershed and are often more fire-adapted than native species and will not only carry fire well but quickly exploit suitable habitat after a fire. The area's strong, gusty winds and naturally hot and dry weather produce a climate conducive to wildfire occurrence and contribute to the rapid spread of fire. Wildfires typically start at the end of a dry cycle, and the exposed soils are most vulnerable at the onset of the wet season.

There have been numerous fires within the watershed over the past five years, many of a suspicious nature (Figure 30). In September 2004, a 1,500-acre fire started south of Kawaihae Road near the egg farm and burned down to Queen Kaʻahumanu Highway, causing the evacuation of 40 homes within the ʻŌuli Ekahi subdivision and 16 homes in the Mauna Kea Uplands subdivision. In May and June of 2005, fires blackened 400 acres at Puʻu Pā on Parker

Ranch lands near the Waimea Airport and 100 acres *makai* of Queen Kaʻahumanu Highway just south of Kawaihae Road. In August 2005, a fire that began near the Lālāmilo Farm lots burned 15,000 acres and led to the evacuation of 4,000 residents of Waikoloa Village. The fire also burned north towards Waikoloa Stream. However, the reduced fuel load from cattle grazing in the area slowed the fire considerably and kept the neighborhoods along Kawaihae Road safe. The August 2005 fire lasted days and required the collective efforts of the Hawaiʻi County Fire Department, volunteer units, U.S. Army, and Hawaiʻi DLNR. In late August 2005, another fire started near the Lālāmilo Farm lots, but because of favorable weather conditions and cattle grazing, it was slower-moving and more-easily contained.

In July 2007, brushfires burned about 10 acres *makai* of Kawaihae Road near the Puʻukoholā Heiau National Historic Site, forcing the evacuation of residents of the Kawaihae transitional housing, and 600 acres *makai* of Māmalohoa Highway near the Waimea Airport. In August 2007, a wind-driven brush fire burned down the slopes above Kamuela View Estates, burning approximately 170 acres. The fire, likely caused by a downed power line, came within a quarter of a mile of homes, until a fire break was cut between the flames and homes. In October 2007, a wildfire burned 550 acres near Spencer Beach Park and Mauʻumae. In July 2008, a fire burned 2-1/2 acres on the south side of Kawaihae Road near mile-marker 66. Another fire burned about 35 acres near the subdivisions of Anekona and ʻŌuli Ekahi in September 2008, causing the evacuation of some homes. While no houses were damaged, the fire came extremely close to 10 homes. In March 2010, roadside mowing operations along Kawaihae Road sparked a fire that burned 630 acres in the lower watershed. A November 2010 fire burned 130 acres within the Kanehoa subdivision, destroying an agricultural out-building, damaging a house, and resulting in the evacuation of the subdivision residents.

**Sediment in the Stream Channel Following the March 2010 Wildfire**




Created by O. Smith Co. 2011

**Figure 30: Waiʻulaʻula Watershed Wildfire History Map (1973-2009)**

Managed grazing is a tool to mitigate the risk of wildfire. Effective fine fuels management via cattle grazing has been demonstrated to slow the spread of wildfire and, therefore, reduce the surface area that is susceptible to sediment runoff. About 90% of fire starts occur along the highways bordering the watershed and away from the stream corridor. With effective grazing management, fire starts can be contained more rapidly, preventing the spread of fire to the sensitive stream corridor. This will protect water quality within Wai'ula'ula stream as well as coastal areas.

While a significant portion of the watershed is used for cattle grazing, parts of the watershed have historically remained ungrazed because they have not been fenced and there has been no water available for cattle. In particular, the lower watershed between 1,200-ft elevation and sea level is currently unfenced. These wildland areas, classified as Agricultural District, are the most fire-prone part of the watershed. These areas have burned several times in the past five years, leaving bare land susceptible to significant erosion. Queen Kaʻahumanu Highway bisects these marginal lands and Kawaihae Road follows the northern boundary, providing access for intentional and accidental fire starts.

Fire-fighting within the Waiʻulaʻula watershed is challenging. Access is difficult and, because of the concern about unexploded ordnance from WWII-era firing exercises in the area, it is normally not considered safe for firefighters to fight the fire on the ground. Rather, they are stationed around the perimeter of the fire, and the Fire Department uses helicopters to drop water on the hot spots. Bulldozers are brought in to cut fire breaks to help contain the fire and protect neighborhoods from its encroachment.

Not only does fire itself damage the natural environment, but the process of fighting the fire also affects the resources of the watershed. Construction of access roads and fire breaks during a fire can create channels for future erosion. Therefore, it is critical that post-fire assessments be performed and restoration activities undertaken, preferably before available heavy equipment is released from the site following a fire.

The Hawaiʻi Wildfire Management Organization (HWMO) is a 501(c)(3) non-profit organization established in 2002 to protect, conserve and enhance resource values in West Hawaiʻi by reducing wildfire frequency and size. The organization's goals are to develop and implement fuels management activities, to provide educational opportunities about wildfire, to conduct fuels management research, to promote the protection of native ecosystems from the effects of wildfire, and to support and facilitate a multi-faceted approach to wildfire prevention and management. Participating agencies and organizations include DLNR, Hawaiʻi County Fire Department, NRCS, U.S. Fish and Wildlife Service (USFWS), U.S. Army, U.S. Forest Service, University of Hawaiʻi Cooperative Extension Service (CES), MKSWCD, and affected landowners and communities.

## 4.3 Unexploded Ordnance

Between 1943 and 1953, the U.S. military used 130,000 acres of land in West Hawaiʻi for training purposes (Figure 31). At least 40% of the area was used for training with live military munitions (Hawaiʻi County 2008), including significant portions of the Waiʻulaʻula watershed. Following the deactivation of Camp Tarawa and the Waikoloa Maneuver Area, the Department of Defense performed cleanup activities, consistent with the standards and technologies of that time. However, within the last decade, unexploded ordnance (UXO) has been found at several sites within Waimea and in and around Waikoloa Village. At least six people have been killed or injured by old artillery rounds since the 1940s (USACOE 2005).

The Formerly Used Defense Sites (FUDS) program, administered by the U.S. Army Corps of Engineers, addresses potential risks on lands formerly owned or controlled by the Department of Defense prior to 1986 (Hawaiʻi County 2008). The Waikoloa FUDS area covers 137,000 acres, of which 50,000 are considered “high risk.” Most of these high risk lands are in or adjacent to the Waiʻulaʻula watershed.  "To date the Army Corps has cleared about 8,000 acres of land and removed approximately 1,800 pieces of live munitions" (Hawaiʻi County 2008: p. 36).  Live ordnance found in the area includes grenades, bazooka rounds, artillery and mortar rounds, land mines, and hedgehog missiles.

As more and more of the region is undergoing development, "the Corps' FUDS team has taken an aggressive approach to reaching current and future homeowners and developers" (Hawaiʻi County 2008: p. 36).  Private land owners who have property in high- or moderate-risk areas that have not yet been cleared are encouraged to contact the USACOE for help in surveying the land for UXO prior to construction.

Because of the risk of unexploded ordnance, the policy of the Hawaiʻi County Fire Department is to not allow firefighters to access those high risk areas on-the-ground to fight wildfires. Rather, they use helicopter water drop operations, fuel breaks, and perimeter defense as a way to control wildfires in these areas.

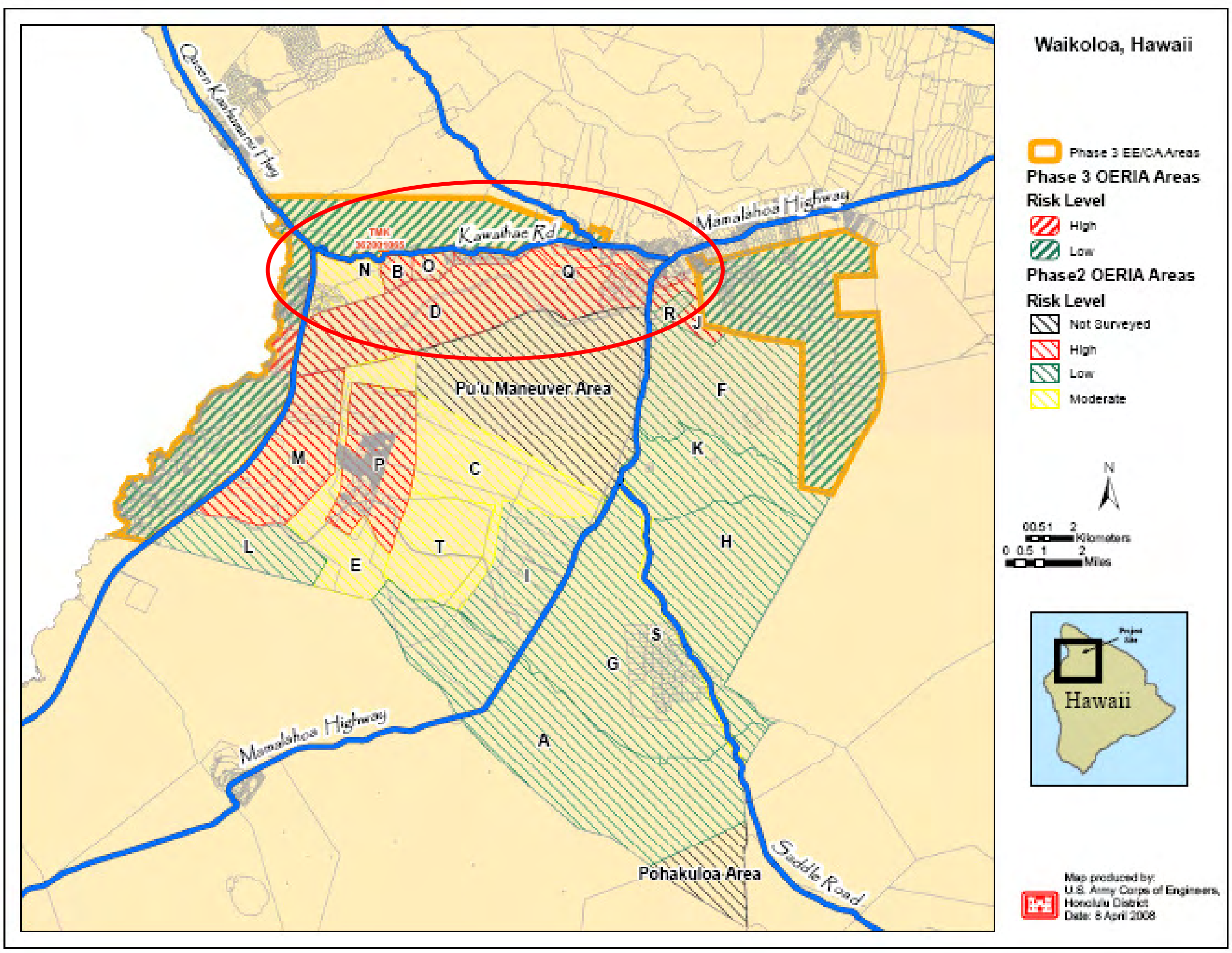



**Figure 31: Formerly Used Defense Sites (FUDS) in South Kohala (from Hawaiʻi County 2008)**

Addressing UXO removal is beyond the scope of this watershed management project. However, implementing projects to facilitate fire-fighting without on-the-ground response that could endangered fire-fighter lives is part of the scope of this plan.

## 4.4 Solid and Hazardous Waste

The old Waimea landfill is located immediately adjacent to Waikoloa Stream, downstream of Sandalwood and adjacent to the transfer station. This unlined, 30-40-ft. deep landfill was closed in 1987 and replaced with the solid waste transfer station. It was covered with approximately two feet of soil and planted with grass. Inspections of the old landfill by DOH in 2001 and 2002 confirmed the presence of an active underground fire (DHHL 2002). As material buried in the landfill decomposes, cracks and sinkholes have also developed in the landfill surface. The landfill is under the jurisdiction of the Hawaiʻi County Department of Environmental Management. According to DHHL (2002), the County applies layers of dirt on a regular basis to suppress the smoke and particulate emissions, and fill cracks and fissures. No information is currently available on the effects of the landfill on stream water quality, though it is likely there is seepage of pollutants from the landfill into the adjacent stream. Water sampling above and below the old landfill would be necessary to determine its effects on water quality. However, addressing any effects of the landfill on water quality is beyond the scope of this watershed management plan.

The County Solid Waste Division Waimea Baseyard and County Solid Waste Transfer Station are also located adjacent to Waikoloa Stream. Trash is deposited at the transfer station into enclosed containers. The containers are removed from the site when they are full, and the waste is transferred to the Puʻuanahulu landfill. Because the transfer station is exposed to the strong trade winds, trash – usually plastic waste – often blows out of the containers downwind, where it gets caught in fences or trees and shrubs along Waikoloa Stream. This trash often ends up in Waikoloa Stream, where it is carried downstream during storm events.

There are several areas within the watershed that are used as dumping grounds. There are unfenced areas in the lower watershed that are accessed by people to abandon vehicles, which are often smashed up and left to rust, spilling fluids on the ground. There are also sections of Waikoloa stream, particularly in Waimea town, where people litter regularly. Because the stream bed is usually dry, people seem to treat it as more of a “back alley” than as a natural asset to be protected. A District-sponsored stream cleanup in April 2008 netted 25 bags of trash, a foam mattress, and several large pieces of rusty metal within a ¼ mile section of stream in town. Parker School classes regularly pick up trash within the stream along the school grounds.

## 4.5 Flooding

Flooding is not normally a threat, unless development has occurred in the floodplain. That being said, flooding has been a problem in the Waimea area for decades, as described in Section 2.2.6. During times of unusually heavy rainfall, the town of Waimea has suffered disruptive flooding. As Waimea has grown over the years, there are greater numbers of structures potentially in harm's way.

Flood control structures have been built (Parker Ranch's grassed drainage channel) and contemplated (proposed concrete channelization of Waikoloa Stream in Waimea town center). Stormwater runoff is currently managed primarily through regulation and by dry wells as a means to reduce flooding potential. As more impervious surfaces are created through increased urban and suburban development, the hardened areas prevent infiltration and generate greater volumes of stormwater runoff. While the runoff may carry relatively smaller pollutant loads, it consists of a greater volume of water, which can lead to more frequent and severe flooding. Low Impact Development (LID) techniques, a relatively new and under-utilized concept in stormwater management, can create less impervious area, generate less surface runoff, and require smaller infrastructure for drainage.

## 4.6 Stream Diversions

There are numerous permitted and unpermitted diversions within the Waiʻulaʻula watershed. So much water is being diverted, in fact, that the watershed's streams are no longer perennial in the lower reaches. The specific amount of water taken from each stream varies daily, and total annual withdrawal amounts are not documented.

There are segments of the Waiʻulaʻula Stream system that are sometimes dry or sometimes have water only in stagnant pools. This creates stress for aquatic life (insects, crustaceans, fish, etc.), which is particularly important given the presence of native species in the stream. Legal and illegal streamflow diversions contribute to this situation. Increases in the amount of diversions have the potential to threaten the freshwater aquatic ecosystem in certain reaches. The timing of diversions is important. Diversions during periods of low streamflow are less significant than diversions during periods of high streamflow, which native fish species are actively migrating upstream. Because of the importance of water resources, this is a potentially sensitive issue.

## 4.7 Climate Change

There is a considerable body of evidence that the global climate has undergone change in the last 50-100 years, and the scientific consensus is that continued change is very likely. In addition to warming, the hydrological cycle is expected to intensify, with more evaporation, more precipitation, and more runoff in certain regions (Huntington 2006). Indeed, these changes have already been detected at the global scale. It is more difficult, however, to predict changes in regional hydrology (some regions could become wetter and some drier) than to predict global averages. One study of possible changes in Hawaiʻi concluded that within a hundred years, rainy season rainfall could decrease and dry season rainfall could increase slightly (Timm and Diaz 2009). Another report predicts increasing temperatures, decreasing net precipitation during the winter (with concurrent decline in streamflow), in addition to increasing sea level (exacerbating high wave inundation), ocean temperatures (leading to coral bleaching), and ocean acidification (negatives effects on coral, disruption of marine food web) (HCA 2009).

The specific impact to the Waiʻulaʻula watershed is unknown. Climate change has the potential to exacerbate other threats to watershed health. The possibility of altered streamflow regimes cannot be ruled out. This would have negative impacts on freshwater availability for domestic and agricultural uses, and survival of native aquatic species. Further, temperature shifts could alter biogeochemical nutrient cycles, thereby altering stream nutrient concentrations and fluxes. Shifts in vegetation communities are possible, which could affect erosion and runoff. Given the obvious trends but the uncertainty about specific regional effects, it is important to protect ecosystems from non-climate stressors in order to promote ecosystem resilience and adaptation (HCA 2009).