Stormwater Assessment Pilot Study in the Waiʻulaʻula Watershed, West Hawaiʻi

Volume 2

Use of the N-SPECT Model to Quantify Direct and Cumulative Impacts

Photo courtesy of USDA NRCS

Submitted by Jené Michaud
University of Hawai'i at Hilo

and

Carolyn Stewart
Marine and Coastal Solutions International

May 2012

A publication of the Hawaiʻi Office of Planning, Coastal Zone Management Program, pursuant to National Oceanic and Atmospheric Administration (NOAA) Award No. NA09NOS4190120 funded in part by the Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resources Management, National Ocean Service, NOAA, United States Department of Commerce. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies.

Recommended Citation

Michaud, J.D. and M.C. Stewart (2012). Stormwater Assessment Pilot Study in the Waiʻulaʻula Watershed, West Hawaiʻi: Use of the N-SPECT model to Quantify Direct and Cumulative Impacts (Vol. 2). Hawaiʻi Office of Planning, Coastal Zone Management Program.

or

Michaud, J.D. and M.C. Stewart (2012). Stormwater Assessment Pilot Study in the Waiʻulaʻula Watershed, West Hawaiʻi (Vol. 1-3). Hawaiʻi Office of Planning, Coastal Zone Management Program.

Acknowledgements

This project benefited from the guidance of the Coastal Zone Management Program, Hawaiʻi State Office of Planning. Jamie Scharf and Tony Kovach of the University of Hawaiʻi at Hilo performed many of the analyses reported herein and contributed significantly to the preparation of this report.

Office of Planning

CZM

Executive Summary

This report describes a modeling study that examined the feasibility of using NOAA's Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT) to predict the impact of new urban development on stormwater runoff volume, nutrient loads, and soil erosion. This was accomplished through a case study that applied the model to fourteen hypothetical new developments in the Waiʻulaʻula watershed on the Island of Hawaiʻi. This watershed was selected because it is in a fast-growing area and contains the only flowing stream in West Hawaiʻi. Each of the new "developments" is located on lands that are currently undeveloped but are slated for future development under the County General Plan. Six categories of development were represented: low-density urban, rural, resort, high-density urban, urban expansion, and industrial.

Stormwater impacts were estimated by comparing pre-development stormwater loads with post-development loads. Assessments were carried out under several precipitation scenarios (average annual and several design storms) and two levels of development (50% build-out and 100% build-out). To examine cumulative impacts, we modeled stormwater loads assuming development of nearly all the land that is slated for future development. To provide a context for interpretation of modeling results, we have reviewed existing studies and placed the hypothetical proposed development in the context of State and County general plans.

N-SPECT predicted that development will triple runoff volume within the parcels that are slated for future development. The exact amount of increase depends on the precipitation scenario and the type of proposed development. Parcels designated for urban expansion were predicted to experience increases of 200-500% and account for about three-quarters of the increased runoff from all parcels. In contrast, an increase of about 45% is expected for areas designated for resort, rural, and low-density urban development. These figures are averages for a development category; values can be higher or lower depending on soils and pre-development land use. In a few of the developments runoff is expected to decrease under some precipitation scenarios.

N-SPECT assumes that nutrient concentrations vary with land use. Development usually increases nutrient concentration and increases runoff volume, resulting in elevated post-development nutrient loads. N-SPECT predicted that development will increase total phosphorus (TP) loads by a factor of 2-8 (depending on precipitation scenario) in the areas slated for high intensity development. In areas slated for low intensity development reductions or very small increases to TP were predicted. N-SPECT predicted that development will increase loads of total nitrogen (TN) by somewhere between 80% and a factor of 7 (depending on precipitation scenario) in the parcels that are slated for high intensity development. Smaller increases (20-50%) are expected in areas slated for low intensity development.

N-SPECT has two options for predicting sediment impacts. The first is to assume that the concentration of total suspended solids (TSS) in storm runoff varies with land use. The second is to use the Revised Universal Soil Loss Equation (RUSLE), which assumes that soil erosion is related to topography, soils, vegetation, and the ability of raindrops to dislodge soil. These two methods of predicting sediment impacts gave different results, with the RUSLE predictions being more credible. RUSLE predicted that development will reduce average annual soil erosion to about 20% of pre-development values. The reductions make sense if one considers that soil cannot erode if it is covered by pavement or buildings.

New developments are typically built in stages and as many as several decades may pass before construction is complete. Predicted impacts at 50% build out are approximately half of what is predicted at full build out. They are not exactly half, however, because rainfall, soils, and topography vary across a proposed development parcel.

In evaluating the significance of impacts it is helpful to place them in the context of the entire 26 mi^2 watershed. The increased runoff resulting from development of all fourteen parcels is only a small percentage (about 9%) of the watershed's total runoff. Comparable figures for TP, TN, and sediment are about 23% and 13%, and 5% respectively. (Figures vary by precipitation scenario). Even at full build-out, developed areas are predicted to contribute only about 15%, 30%, 20%, and 5% of the watershed's total load of runoff, TP, TN, and sediment, respectively. This reflects the fact that the County General plan anticipates that most of the watershed will be remain undeveloped, with forest and grazing lands predominating.

This study made no effort to validate the model by comparing model predictions to field data. Although there are some field data for the study watershed, they are not comprehensive enough to suffice for model validation. Model parameters were based on C-CAP vegetation/land use data, standard soil datasets, default values for pollutant concentrations, and default relationships between vegetation/land use and infiltration rate. Model outputs are predicated on parameter values and model assumptions so it is important to evaluate modeling results accordingly.

N-SPECT is implemented in a GIS environment. This facilitates the acquisition and processing of input data. The data required by the model is readily available, but, even so, implementing and running the model took about six person-months. N-SPECT is well suited for "first cut" estimates of impacts to runoff volume, nutrient loads, and soil erosion. It is equally well-suited for evaluating direct impacts and cumulative impacts. Interpretation of the ecological significance of load numbers is an exercise left to the user. Notably, N-SPECT is not designed to predict impacts to peak flows, nor to evaluate the effectiveness of proposed mitigation measures intended to reduce stormwater impacts.

Table of Contents

1. Introduction 8

1.1 Purpose and Scope of Study 8
1.2 Design of study 9
1.2.1 Summary 9
1.2.2 Watershed Selection 10
1.2.3 Strategy for Selecting Areas to be "Developed" 11

2. Model Description 13

2.1 Summary of N-SPECT Assumptions and Capabilities 13
2.2 Prediction of Runoff Using the SCS Curve Number (CN) Method 14
2.3 Relationship between Land Use and Runoff Parameters (Curve Numbers) 15
2.4 Prediction of Pollutant Loads and Concentrations 15
2.5 Mechanistic Method (RUSLE) for Sediment/Erosion Predictions 17
2.6 Relationship between Land Use and RUSLE Parameters 18
2.7 Using RUSLE to Predict Erosion for Design Storms 18

3. Application of the Model to the Study Watershed 19

3.1 Identification of Parcels Slated for “Development” 19
3.1.1 Summary 19
3.1.2 Methods 19
3.1.3 Results. 20
3.2 Implementation of the Model 25
3.2.1 Preprocessing of Datasets 25
3.2.2 Topography and Land Cover Data 26
3.2.3 Soils Data 26
3.2.4 R-Factor 26
3.2.5 Precipitation Data 26
3.2.6 Pollutant Coefficients (Average Concentrations) 27
3.3 Running the Model 28

4. Modeling Results 29

4.1 Direct Impacts Resulting from Full Build Out 29
4.2 Two Levels of Development (50% and 100% Build Out) 29
4.3 Cumulative Impacts 36
4.4 Interpretation of Results 39

5. Critique of Model 41

5.1 Discussion 41
5.2 Strengths and Limitations 42
5.3 Recommendations for Model Enhancements 44

6. References 46

Table of Contents, cont.

APPENDIX A – Predicted Impacts for Average Annual Scenarios 48

Table A.1. Predicted change in annual average runoff at full build out.
Table A.2. Predicted change in annual average load of total nitrogen (TN) at full build out.
Table A.3. Predicted change in annual average load of total phosphorus (TP) at full build out.
Table A.4. Predicted change in average annual soil erosion sediment load at full build out, according to the RUSLE model.

APPENDIX B – Predicted impacts for Design Storm Scenarios..... 53

Table B.1. Predicted change to runoff for design storms and full build out.
Table B.2. Predicted change to total phosphorus (TP) loads for design storms and full build out.
Table B.3. Predicted change to total nitrogen (TN) loads for design storms and full build out.
Table B.4. Predicted change to MUSLE erosion for design storms and full build out.

APPENDIX C: Two Development Levels..... 58

Table C.1.Predicted change to 2-yr 24 hr runoff for 100% and 50% build out.
Table C.2. Predicted change to 2-yr 24 hr total phosphorus (TP) loads for 100% and 50% build out.
Table C.3. Predicted change to 2-yr 24 hr total nitrogen (TN) loads for 100% and 50% build out.
Table C.4. Predicted change to average annual RUSLE erosion for 100% and 50% build out.

Glossary..... 63

LIST of FIGURES

Figure 1. Location of the study watershed. 10

Figure 2. Parcels slated for future urban development and modeled by N-SPECT as new developments. 21

Figure 3. Existing pre-development land use in the upper (eastern) half of the watershed. 23

Figure 4. Existing pre-development land use for parcels in the lower (western) half of the watershed. 24

Figure 5. Waiʻulaʻula watershed subbasins used during modeling. 27

Figure 6. Predicted change in runoff depth (shown as colors) and volume (% changes) resulting from new development. 30

Figure 7. Predicted change in total nitrogen yield (shown as colors) and loads (% changes) resulting from new development. 31

Figure 8. Predicted change in total phosphorus yield (shown as colors) and loads (% changes) resulting from new development. 32

Figure 9. Predicted change in average annual soil erosion shown as yields (colors) and loads (% changes), calculated using the RUSLE method. 33

Figure 10. Change in load for different precipitation scenarios. 34

Figure 11. Runoff and pollutant loads at two levels of development (50% and 100% build out). 35

Figure 12. Comparison of loads for existing development, future development, and other land use categories. 37

LIST of TABLES

Table 1. Explanation of development categories in the County of Hawaiʻi General Plan Land Use Pattern Allocation Guide (LUPAG). 12

Table 2. Summary of major sub-models used in N-SPECT. 14

Table 3. Curve Numbers and cover management values for each C-CAP land cover class. 16

Table 4. Default pollutant coefficients for each C-CAP land cover class. 17

Table 5. Parcels that fall into N-SPECT's definition of low intensity development. 22

Table 6. Parcels that fall into N-SPECT's definition of high intensity development. 22

Table 7. Datasets used during N-SPECT modeling. 25

Table 8. Cumulative loads from existing and proposed development. 38

1. Introduction

1.1 Purpose and Scope of Study

The purpose of this study was to evaluate the usefulness of NOAA's Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT) in assessing the impact of new development on stormwater. This was accomplished through the use of a case study involving application of N-SPECT to hypothetical new developments in the lightly developed Waiʻulaʻula watershed, which is located on the Island of Hawaiʻi. This watershed was selected because it is in a fast-growing area of leeward Hawaiʻi Island (hereinafter West Hawaiʻi) and contains the only flowing stream in West Hawaiʻi. Moreover, the stream supports native fauna and discharges near a reef in a bay with water quality concerns. Thus, although the watershed is in generally good condition, there are legitimate concerns about future degradation of habitat and water quality (MKSWCD 2011).

This study is part of a larger effort to critique and improve methods used in Environmental Impact Statements (EIS) to assess stormwater impacts in Hawaiian Watersheds. According to Federal and State guidelines *(*40 CFR 1508.7 and HAR §11-200-16), EIS should address cumulative impacts in addition to impacts triggered directly by the proposed action (hereinafter "direct" impacts). Cumulative effects refer to actions whose impacts are small individually but contribute to significant impacts when considering the sum of all past, present, and future actions. N-SPECT is particularly well-suited for addressing cumulative impacts.

This document is the second of the three-volume report that examines several methods of stormwater assessment using the Waiʻulaʻula watershed as a pilot study. Refer to Volume One for an overview and recommendations for an improved practice of stormwater assessment. Refer to Volume Three for an examination of typical methods that have been used in the past, and a comparison with an approach that was recommended in related prior investigation (Department of Geography and Environmental Science and PBR Hawaiʻi 2011). Volume Three shows how N-SPECT can be used, in a limited fashion, to model the effects of Best Management Practices.

1.2 Design of study

1.2.1 Summary

N-SPECT was used to predict changes to stormwater pollutant loads occurring as the result of hypothetical new urban development. The areas to be "developed" consisted of those parts of the study watershed that are currently undeveloped but are slated for future development under the County of Hawaiʻi's Land Use Pattern Allocation Guide (LUPAG). The LUPAG is designed to guide development of the island. Fourteen parcels met these criteria.[1] The N-SPECT model was used to predict pre-development and post-development stormwater pollutant loads.[2] The difference between pre-development and post-development pollutant loads represents the impact of development. To gain perspective on the results, impacts from new developments were compared to loads from the entire watershed. Cumulative impacts were calculated as the sum of loads from existing developments and the loads from the future hypothetical developments. The stormwater parameters predicted by the model were total phosphorus (TP) loads, total nitrogen (TN) loads, stormwater runoff volume, and soil erosion.

N-SPECT treats developed areas as either low-impact development or high-impact development. Each parcel slated for future development was assigned to one of these categories based on its LUPAG designation. Two levels of development were considered: 50% build out and 100% build out. Each parcel was divided into two equal parts in order to simulate the 50% development scenario.

Modeling was conducted at the average annual time scale and also for the 1-hour 10-year storm, the 24-hour 2-year storm, and the 24-hour 100-year storm. These so-called design storms or "events" are used in engineering design.[3] The 1-hr 10-yr event has traditionally been used in Hawaiʻi County when designing drainage works. Federal and State guidelines recommend the use of the 24-hr 2-yr event in calculating nutrient pollutant loads regulated under the Clean Water Act. For erosion, however, Federal and State guidelines recommend calculating average annual values. The 24-hr 100-year storm represents a worst case scenario, relevant because the greatest ecological impacts often occur as the result of exceptional storms and nonlinear watershed response.

This study made no effort to validate the model by comparing model predictions to field data. Although there are some field data for the study watershed, they are not comprehensive enough to suffice for model validation.

The larger purpose of the study was to evaluate the feasibility of using N-SPECT to assess stormwater impacts. Such an assessment would normally be conducted during the preparation of an Environmental Impact Statement.

---

[1] In this report "parcel" is used to denote a particular geographic area but is not based on lots representing particular TMK.

[2] Loads are the amount (mass) of a pollutant exported from a given are in a given amount of time or during a given storm.

[3] To understand design storms, consider a hypothetical example in which the 1-hour 10-year rainstorm is 2.4 inches. This storm delivers 2.4 inches in one hour and has a 10-yr recurrence interval. That is to say that in any given year there is a 1 in 10 chance that the greatest 1-hour rainfall will exceed 2.4 inches.

1.2.2 Watershed Selection

The Wai'ula'ula Watershed stretches from the top of Hawai'i Island's Kohala and Mauna Kea volcanoes to the western (leeward) coast of the island (Figure 1). It enters the ocean in inner Kawaihae Bay near the Mauna Kea Beach Resort, a distance of less than 15 miles. The entire watershed is 50 mi^2 (130 km^2), but the upper section on Mauna Kea is thought to be non-contributing, resulting in an effective watershed area of 26 mi^2 (68 km^2). The contributing portions of the watershed include high elevation forests in the conservation district, urban areas in the town of Waimea (Kamuela) and near the coast, grazed grasslands (moderate elevations) and arid to semi-arid grazed scrublands (lower elevations). There is a very small amount of cultivated land.

This watershed was selected as the study site for several reasons. It is expected to experience substantial development in the future and is the only watershed in leeward Hawai'i Island that experiences regular flow to the ocean. The stream is perennial (flows continuously) in its upper reaches and intermittent (flows for weeks to months) in its lower reaches, whereas all other streams in West Hawai'i are ephemeral (flow only briefly after rainstorms). The Wai'ula'ula watershed is also an interesting case study because it is flows into an embayment with coral reefs, provides habitat for numerous native aquatic species, and already has a watershed plan (MKSWCD 2011).

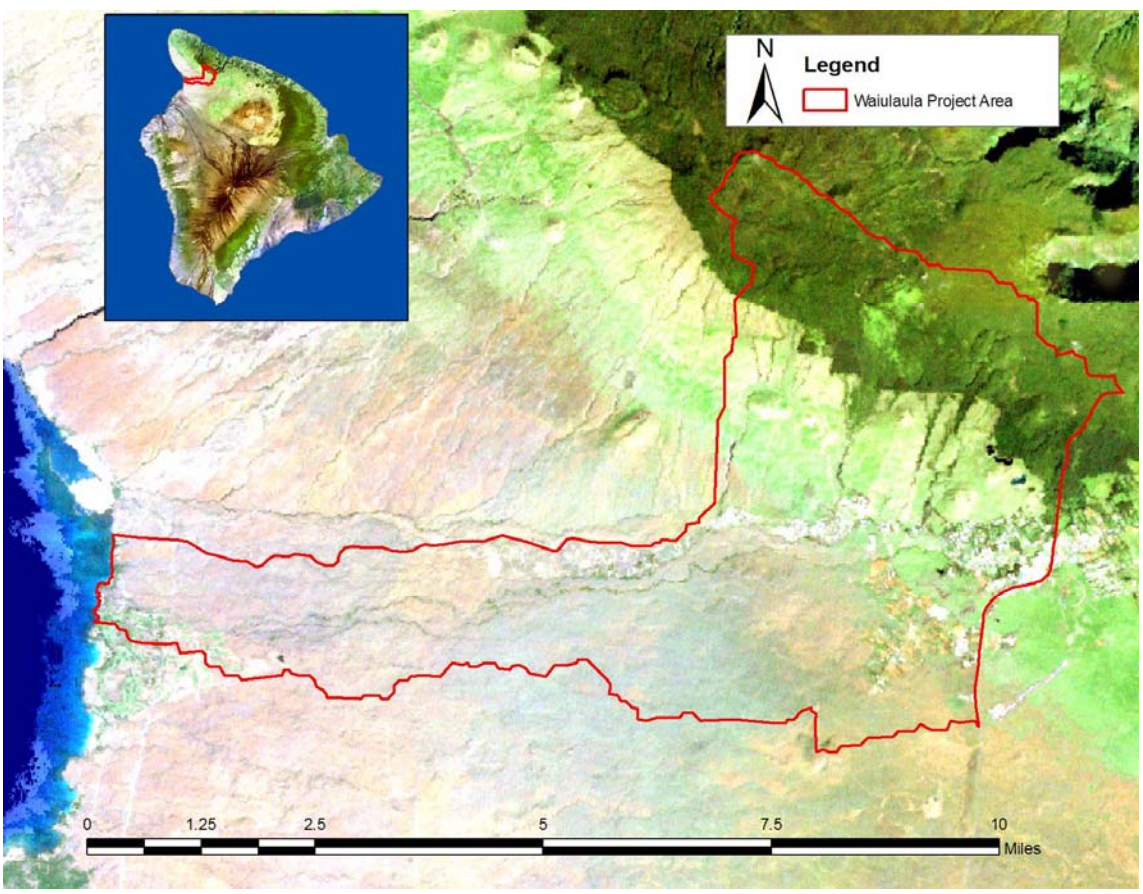


Figure 1. Location of the study watershed.

1.2.3 Strategy for Selecting Areas to be "Developed"

To be selected for "development" (future hypothetical developments), parcels had to meet two criteria. First, their current condition must be largely undeveloped. Secondly, they must be slated for future development under the County of Hawaiʻi's Land Use Pattern Allocation Guide (LUPAG) (County of Hawaiʻi 2005).

The LUPAG, which is part of the County General Plan, is intended to be a "well-balanced land use pattern capable of meeting the future needs of the County. There are no universal standards for determining the amount of land needed in the future for each land use or activity located within an area. Estimates can be made, however, of the future land use acreage allocation for each use. The land use pattern is a broad, flexible design intended to guide the direction and quality of future developments in a coordinated and rational manner. The LUPAG Map indicates the “general location of various land uses in relation to each other.” (General Plan) GIS versions of this map are available from the Hawaiʻi Office of Planning GIS website.

The land use categories considered by the LUPAG includes conservation lands, two types of agricultural uses (extensive agriculture and important agricultural lands) and several categories representing different types and intensities of urban development. Refer to Table 1 for a description of the typical uses within these categories.

The following categories are present in the Waiʻulaʻula watershed:

- Low density urban
- Medium-density urban
- High-density urban
- Urban expansion
- Resort node, and
- Industrial

Table 1. Explanation of development categories in the County of Hawai'i General Plan Land Use Pattern Allocation Guide (LUPAG) (County of Hawai'i 2005).

Low density urban:	Residential, with ancillary community and public uses, and neighborhood and convenience-type commercial uses; overall residential density may be up to six units per acre.
Resort node	These areas include a mix of visitor-related uses such as hotels, condominium-hotels (condominiums developed and/or operated as hotels), single family and multiple family residential units, golf courses and other typical resort recreational facilities, resort commercial complexes and other support services. Only Major Resort Areas are identified as Resort Nodes on the LUPAG Map.
Rural	This category includes existing subdivisions in the State Land Use Agricultural and Rural districts that have a significant residential component. Typical lot sizes vary from 9,000-square feet to two acres. These subdivisions may contain small farms, wooded areas, and open fields as well as residences. Allowable uses within these areas, with appropriate zoning, may include commercial facilities that serve the residential and agricultural uses in the area, and community and public facilities.
Urban Expansion	Allows for a mix of high density, medium density, low density, industrial, industrial-commercial and/or open designations in areas where new settlements may be desirable, but where the specific settlement pattern and mix of uses have not yet been determined.
Industrial	These areas include uses such as manufacturing and processing, wholesaling, large storage and transportation facilities, light industrial and industrial-commercial uses.

2. Model Description

The Non-Point Source Pollution and Erosion Control Tool (N-SPECT) was developed by the Coastal Services Center of the U.S. National Oceanic and Atmospheric Administration (NOAA) with the goal of estimating the impact of land use change on the amount of pollutants delivered to coastal waters (NOAA 2004, 2009). The most recent version of the model (1.5.1) is implemented in a Geographical Information System (GIS) framework as an add-on to ArcGIS, which is a commercial software package that enjoys widespread use. It is possible that future versions of the model will not be implemented within an ArcGIS framework, however, because of incompatibilities with ArcGIS version 10.0 and higher.

N-SPECT uses raster input data (values arranged on a regular grid) and performs calculations on a cell-by-cell basis. Output data is available for each cell, which typically represents a 30 m by 30 m area.

2.1 Summary of N-SPECT Assumptions and Capabilities

The N-SPECT model can be used to quantify pre-development and post-development stormwater runoff (as a volume), stormwater pollutant concentrations (as mass per volume of water), and stormwater pollutant loads (as mass per time exported by the watershed or any subwatershed). The pollutants that can be modeled include total nitrogen (TN), total phosphorus (TP), total lead, total zinc, sediment (TSS option), and soil erosion (RUSLE option). The sub-models used by N-SPECT are summarized in Table 2.

In addition to modeling the average annual loadings, N-SPECT can estimate runoff, pollutant loads, and pollutant concentrations for design storms, for example the 24-hour 100-year rainstorm. The user must provide rainfall for the design storm. N-SPECT is a spatially distributed raster model with a typical spatial resolution of 30 meters. Results can easily be averaged over watersheds, sub-watersheds, or development parcels.

N-SPECT is not designed to predict discharge (peak flows), baseflow, baseflow loads, nor evaluate the impact of BMPs. In standard operation the model is not able to discriminate between presence or absence of BMPs, nor predict the impact of any particular BMP.

Land cover is a key parameter of model. Using the standard parameterizations, land cover types include grassland, forest, cultivated land, scrub, low-intensity development, and high intensity development. For any given soil group, each land cover type has a different Curve Number (CN), a parameter that determines the amount of runoff. A modified version of the SCS CN model is used to predict average-annual stormwater runoff.

N-SPECT model multiplies the runoff volume by assumed concentrations of pollutants (TN, TP, TSS, etc) estimate loads. The pollutant concentrations vary by land cover; for any given land cover types the user may enter custom values or use default concentrations.

There is an option to estimate sediment loads using the RUSLE erosion model and a module for calculating the sediment delivery ratio (SDR, the percentage of eroded sediment that is transported to the watershed outlet).

2.2 Prediction of Runoff Using the SCS Curve Number (CN) Method

N-SPECT calculates total runoff using the flow direction grid and the Soil Conservation Service Curve Number model (U.S. Soil Conservation Service, 1986).

This model assumes that some rainfall must be retained or “abstracted” before runoff can commence. The curve number method is used to predict direct runoff resulting from excessive rainfall. The method has been further developed to make estimates for annual runoff or individual storm event runoff. The runoff curve number (CN) is based on an area’s hydrologic soil group and land use or land cover.

Table 2. Summary of major sub-models used in N-SPECT.

Parameter	N-SPECT sub-model or assumptions
Annual Erosion	RUSLE + SDR equation (Renard, *et al*. 1997, Williams 1975)
Storm Event Erosion	MUSLE (Williams and Berndt 1977)
Runoff	SCS Curve Number model predicts runoff volume for each grid cell. The flow direction grid is used to determine total runoff volume for all upstream grid cells.
Pollutant Concentrations	The model provides default Event Mean Concentration values for each pollutant and each land cover class. (Adamus and Bergman 1995, US EPA 1983) In the model, Event Mean Concentration is called the "pollutant coefficient". Default values are available for TP, TN, TSS (not used because RUSLE is considered superior) , zinc (not used), and lead (not used).
Pollutant Loads	Loads are calculated as the product of runoff volume and pollutant concentration.

According the SCS model, runoff volume (Q) is calculated according to the following equations:

Average Annual $Q = (P - (I_a * D))^2 / [(P - (I_a * D)) + (S * D)]$

Storm Event $Q = (P - I_a)^2 / [(P - I_a) + S]$

where

I_a = initial abstraction (in) = 0.2 * S

S = potential maximum retention after runoff begins (in) = (1000 / CN) – 10

Q = runoff (in)

P = rainfall (in)

CN = runoff curve number (ranges between 0 and 100)

D = number of raining days

Note: If $(P - I_a) < 0$, then Q = 0

2.3 Relationship between Land Use and Runoff Parameters (Curve Numbers)

Soil Conservation Service Curve Numbers (CN) represent the infiltration of precipitation into the soil. CN play a key role in N-SPECT's runoff calculations. CN vary depending on soil hydrologic group (A-D) (Table 3). Group A soils (typically sand/gravel) have the highest infiltration potential, and Group D soils (typically clay soils) have the lowest infiltration potential. Group B soils (typically silt with fine to moderately course textures) have a moderate infiltration rate and Group C soils (typically sandy clay with a moderately fine to fine texture) have a low infiltration rate. N-SPECT includes default CN values associated with C-CAP land cover datasets (U.S Soil Conservation Service, 1986) N-SPECT also allows the user to modify these default values or specify entirely new values (NSPECT Technical Guide Runoff Estimation 12).

2.4 Prediction of Pollutant Loads and Concentrations

N-SPECT combines estimates for runoff with pollutant coefficients to obtain values for the total amount of pollutants (phosphorus, nitrogen, etc.) and sediment concentration (TSS) for each cell. These pollutant coefficients are based on the event mean concentrations (EMC) of pollutants in runoff coming from each land cover type (Table 4). EMC values vary with land cover type and ideally are derived from local water quality sampling data. If local water quality data are not available, default values from the N-SPECT database may be used. Default values are based on studies conducted across the United States (see Table 4 for references). The coefficients are used to create a pollution concentration grid that represents an average concentration (mg/L) for each land cover polygon.

A crude estimate of erosion is made by calculating the total suspended solids using the above methods based on event mean concentrations occurring in runoff. These concentrations are multiplied by the predicted runoff from a cell. Alternative methods to calculate erosion are described in the next section.

Table 3. Curve Numbers and cover management values for each C-CAP land cover class. The cover management factors are used in RUSLE.

C-CAP Land Cover Class	Curve Numbers (Listed by Hydrologic Soil Group) A	B	C	D	Cover Management Factor
High Intensity developed	89	92	94	95	0
Low intensity developed	61	75	83	87	0.03
Cultivated Land	67	78	85	89	0.24
Grassland	39	61	74	80	0.05
Evergreen Forest	30	55	70	77	0.004
Scrub/Shrub	30	48	65	73	0.014
Bare Land	77	86	91	94	0.7
Unconsolidated Shore	0	0	0	0	0.003
Water	0	0	0	0	0

Table 4. Default pollutant coefficients for each C-CAP land cover class

C-CAP Land Cover Class	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	References
High Intensity developed	0.47	2.22	71	Adamus and Bergman 1995
Low Intensity developed	0.18	1.77	19.1	Adamus and Bergman 1995
Cultivated land	0.42	2.68	55.3	Adamus and Bergman 1995
Grassland	0.48	2.48	55.3	Adamus and Bergman 1995
Evergreen Forest	0.05	1.25	11.1	Adamus and Bergman 1995
Scrub/Shrub	0.05	1.25	11.1	Adamus and Bergman 1995
Bare Land	0.12	0.97	70	US EPA 1983
Unconsolidated Shore	0.12	0.97	70	US EPA 1983
Water	0	0	0	n/a

2.5 Mechanistic Method (RUSLE) for Sediment/Erosion Predictions

N-SPECT has an option for calculating average annual sediment loss using a revised version of the Universal Soil Loss Equation (USLE). The principles behind this equation were developed in 1965 and intended for use as a tool for soil conservation on croplands (Wischmeier and Smith 1978). Subsequent changes to the USLE have expanded its applicability to additional land cover types and individual storm events (Renard *et al.* 1997). The current standard for estimating annual erosion is the Revised Universal Soil Loss Equation (RUSLE, Renard, *et al.* 1997), which is stated as

$$A = R * K * L * S * C * P$$

Where:

A = average annual soil loss

S = slope steepness factor

R = rainfall/runoff erosivity factor

C = cover management factor

K = soil erodibility factor

P = supporting practices factor

L = slope length factor

RUSLE provides an estimate of gross erosion from hillslopes, but does not indicate how much eroded soil is actually transported by streams. This additional step is modeled based on the Sediment Delivery Ratio (SDR) (Williams 1975) which accounts for particle size, distance to perennial stream, drainage channel slope, channel roughness and channel depth. Multiplication of the resulting sediment delivery ratio grid by the annual soil loss grid from the previous step will produce a true annual sediment yield grid. The SDR equation (Williams 1975) is as follows:

$$SDR = 1.366 * 10^{-11} * (DA)^{-0.0998} * (ZL)^{0.3629} * (CN)^{5.444}$$

Where:

DA = drainage area (km^2)

ZL = the relief-length ratio (m/km)

CN = SCS curve number

2.6 Relationship between Land Use and RUSLE Parameters

The cover management factor (C-Factor) values are an index used to represent the effect of plants, soil cover, below-ground biomass, and soil-disturbing activities on soil erosion. The lower the cover factor, the better the vegetative cover is at preventing erosion. The higher the cover factor, the more erosion will result in that area. In N-SPECT, C-Factor varies by land use type. The model has default values for each land use category (Table 3) or users can enter custom values for any land use category.

2.7 Using RUSLE to Predict Erosion for Design Storms

For modeling erosion from individual storm events, N-SPECT uses a modified version of the soil loss equation (MUSLE, Williams and Berndt 1977). The MUSLE coefficients were initially developed empirically based on limited data for Texas and the southwestern United States. The following variation of the standard equation has been developed for Oahu, Hawaiʻi and has been used for this study:

$$S = 18.943 * (Q * qp)^{0.877} * K * C * P * LS$$

Where

S = sediment yield from an individual storm (tons)

Q = storm runoff volume (acre-feet)

qp = peak runoff rate (cubic feet per second)

K = soil erodibility factor

C = cover management factor

P = supporting practices factor

L = slope length factor

S = slope steepness factor

3. Application of the Model to the Study Watershed

3.1 Identification of Parcels Slated for "Development"

3.1.1 Summary

The Hawaiʻi County General Plan is intended to guide future growth and development. It contains Land Use Pattern Allocation Guide (LUPAG) maps that describe the future location, type, and intensity of different land uses. The LUPAG maps were used to identify the location of future urban developments and high resolution satellite imagery was used to identify areas that are not currently developed. Overlaying the LUPAG maps onto the imagery allowed us to identify parcels that are not currently developed but are slated for future urban development. Fourteen parcels were identified, including nine falling into N-SPECT's category of low impact development and five that fall into N-SPECT's category of high impact development.

3.1.2 Methods

GIS versions of the County of Hawaiʻi LUPAG maps were used to exclude those portions of the watershed that are unlikely to ever be developed (conservation, agriculture, and open space designations). The remaining areas (urban, rural, resort, or industrial designations) were inspected to determine whether or not they are currently developed. This was accomplished by examining DOQ imagery, georeferenced versions of USGS topographic maps and, occasionally, Google Maps. For some parcels, field checks were used to ground-truth the interpretation of the imagery. ArcMap version 9.3.1 was used for data overlays and digitizing of polygons.

The following data were used during parcel identification:

- DOQ imagery: DigitalGlobe, Longmont, Colorado, 2002-2004. <www.digitalglobe.com>
- DRG (scanned 7 ½ minute topographic maps: U.S. Geological Survey, Western Geographic Science Center, December 2004
- LUPAG maps as GIS polygons: County of Hawaii, 2005. Obtained from the State of Hawaii-Office of Planning GIS Program < http://hawaii.gov/dbedt/gis/> (accessed 08/20/11)
- Watershed boundary GIS polygons. Obtained from the State of Hawaii-Office of Planning GIS Program < http://hawaii.gov/dbedt/gis/>, who lists the source as GDSI, 1995. (accessed 09/13/11)
- State Land Use District Boundaries. Data from the State Land Use Commission and obtained from the State of Hawaii-Office of Planning GIS Program < http://hawaii.gov/dbedt/gis/>, who lists the source as GDSI, 1995. (accessed 09/13/11)

Undeveloped parcels so identified were digitized to produce GIS polygons. Polygons were separated by LUPAG designation. There is a very small amount of undeveloped land in the medium-density urban category, but it was not included because the acreage is insignificant.

N-SPECT treats new development as either low-intensity or high-intensity (see Box 1 for details). Parcels with LUPAG designations of low density urban, resort node, and rural were assigned to the low-intensity development category, and parcels with LUPAG designations of urban expansion or industrial were assigned to the high-intensity development category.

Each parcel was divided into two approximately equal halves in order to conduct the modeling scenarios at 50% build out.

Box 1. N-SPECT's definition of low- and high- intensity development.

High Intensity (Solid Cover) development includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of different land uses. The High-Intensity category contains areas in which a significant land area is covered by concrete and asphalt or other constructed materials. Vegetation, if present, occupies <20% of the landscape. Examples of such areas include apartment buildings, skyscrapers, shopping centers, factories, industrial complexes, large barns, airport runways, and interstate highways.

Low Intensity (Mixed Pixels) development includes areas with a mixture of constructed materials (e .g. roofing, metal, concrete, and asphalt) and vegetation or other cover. Constructed materials account for 50-79% of total area. These areas commonly include single-family housing areas, especially in suburban neighborhoods, but may include scattered surfaces associated with all types of land use. As the percentage of constructed material cover decreases, this category grades into Cultivated, Grassland, Woody, and other land-cover classes. A large building surrounded by several acres of grass, for example, might appear as one or more pixels of High-Intensity Developed Land, one or more pixels of Low Intensity Developed Land, and many pixels of Grassland.

3.1.3 Results.

The analysis identified 14 parcels representing nine low-intensity urban areas and five high-intensity urban areas, for use in NSPECT analysis of the Waiʻulaʻula watershed (Figure 2 and Tables 4 and 5). For existing pre-development land cover/use, refer to Figures 3 and 4.

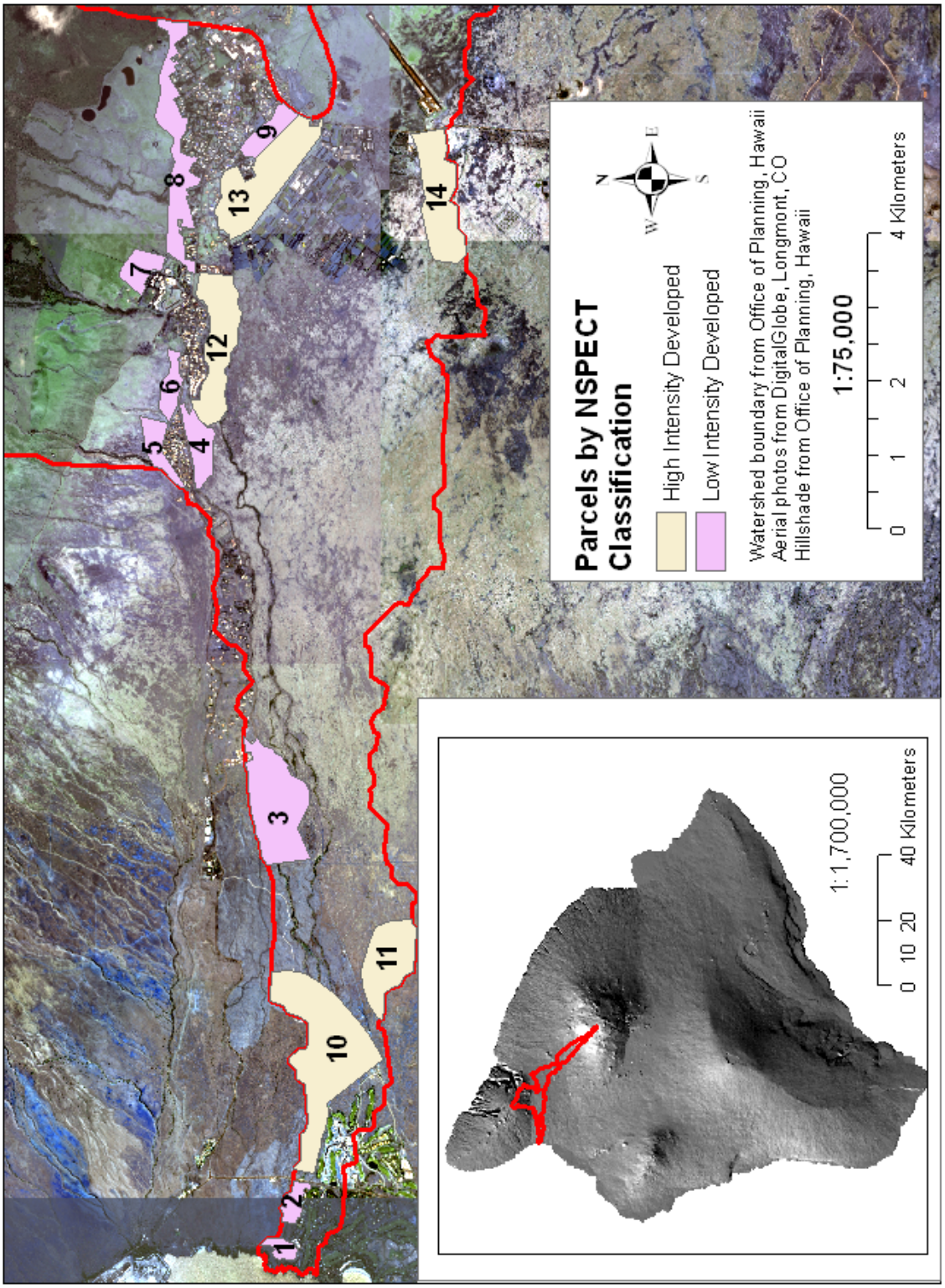


Figure 2. Parcels slated for future urban development and modeled by N-SPECT as new developments. Refer to Tables 5 and 6 for detailed information about parcels.

Tables 5 and 6. *Characteristics of parcels slated for future urban development under the County LUPAG and modeled by N-SPECT as new developments. Refer to Figure 2 for the location of parcels and Table 1 for an explanation of the various categories of future development.*

Table 5. Parcels that fall into N-SPECT's definition of low intensity development.

Parcel ID	Area (Km^2)	Area (acres)	LUPAG Category of Future Development	Existing Land Cover
1	0.095	23.4	low density urban	Scrub/Shrub, with some Low-intensity Developed and Bare Land
2	0.129	31.9	resort node	Low Intensity Developed. shrub/scrub, and grassland
3	1.009	249.2	rural	Scrub/Shrub & Bare Land
4	0.295	73.0	low density urban	Bare Land
5	0.228	56.4	low density urban	Grassland
6	0.187	46.2	low density urban	Grassland
7	0.218	53.8	low density urban	Grassland
8	0.826	204.2	low density urban	Grassland
9	0.223	55.2	low density urban	Grassland

Table 6. Parcels that fall into N-SPECT's definition of high intensity development.

Parcel ID	Area (Km^2)	Area (acres)	Category of Future Development	Existing Land Cover
10	1.695	418.8	urban expansion	Grassland
11	0.644	159.0	urban expansion	Grassland
12	0.809	199.8	urban expansion	Grassland
13	0.996	246.1	urban expansion	Grassland
14	0.776	191.9	industrial	Grassland

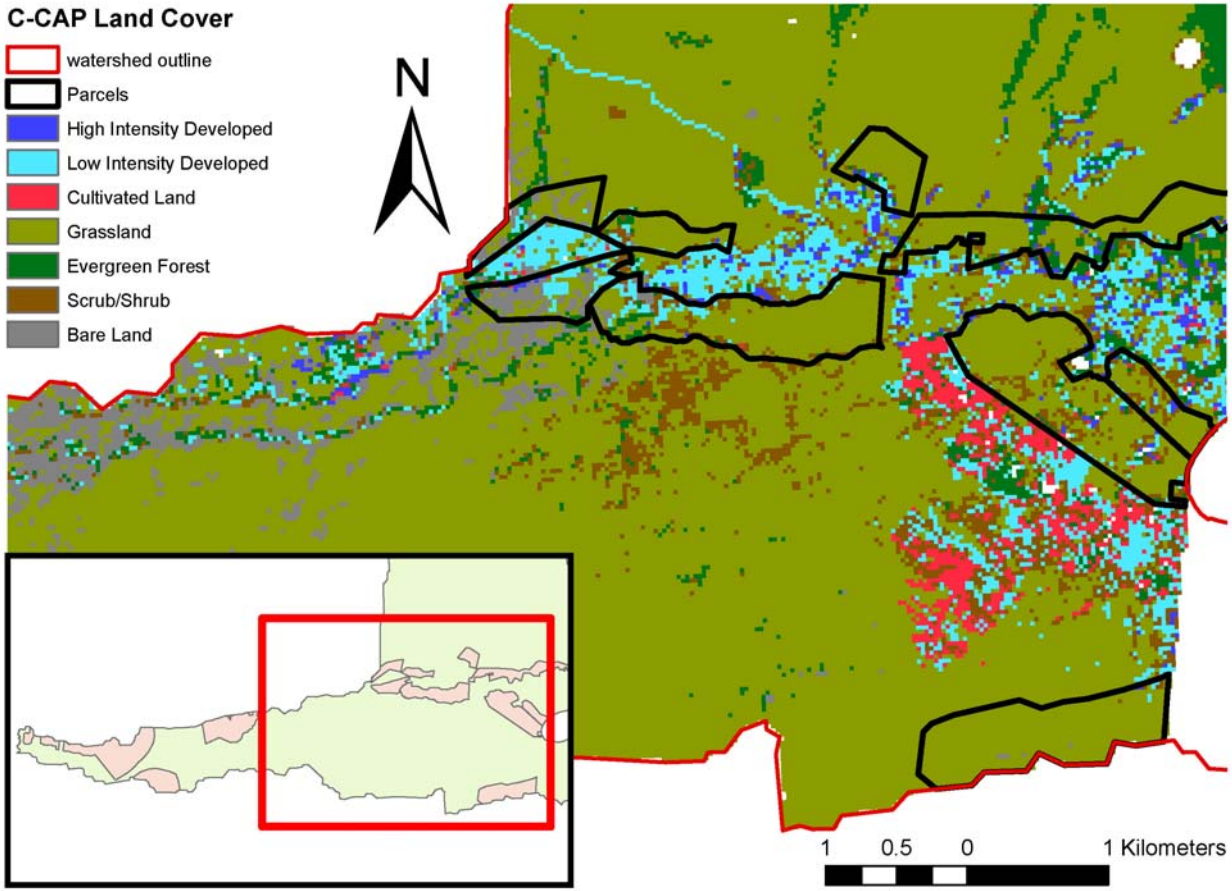


Figure 3. Existing pre-development land use in the upper (eastern) half of the watershed.

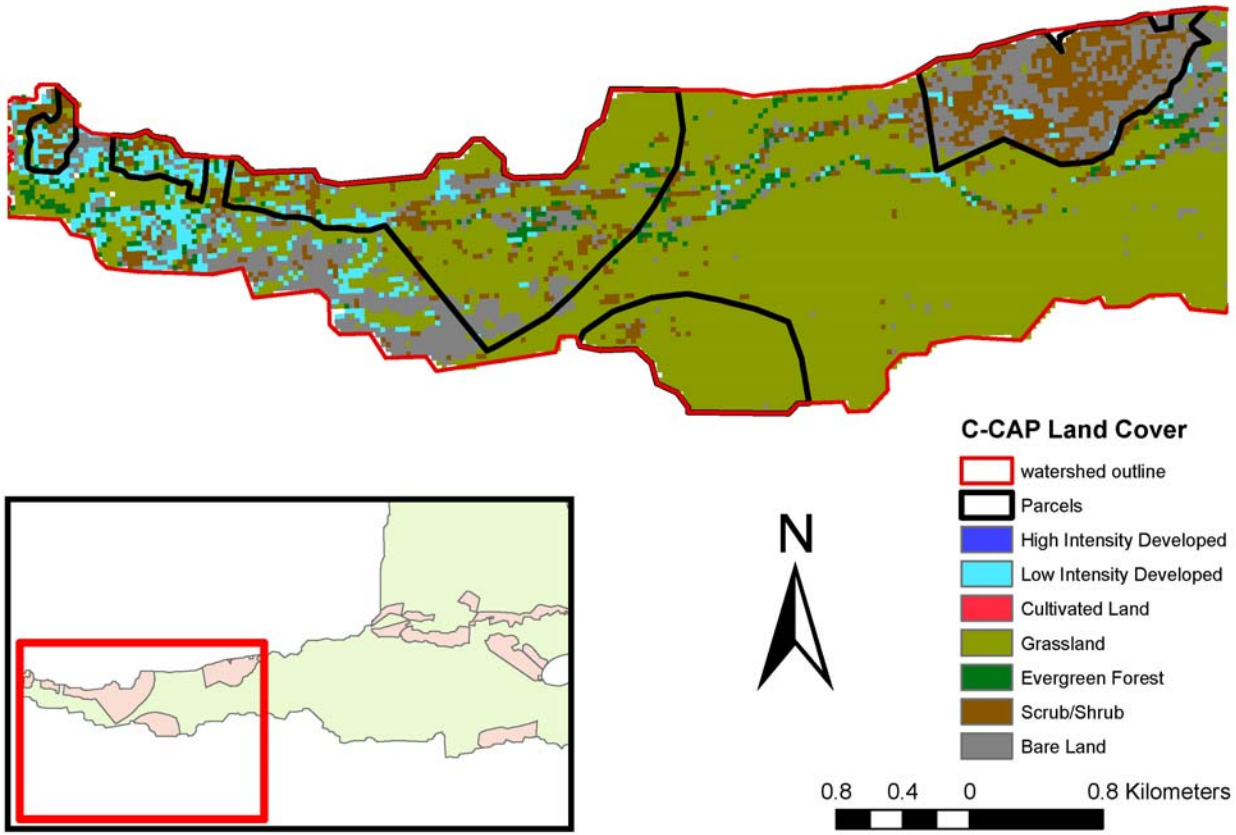


Figure 4. Existing pre-development land use for parcels in the lower (western) half of the watershed.

3.2 Implementation of the Model

3.2.1 Preprocessing of Datasets

All analyses were performed using ArcGIS 9.3.1 and N-SPECT model version 1.5.1. All layers were projected into UTM zone 5N and clipped to watershed to speed processing time. Raster layers were 30m x 30m resolution. A variety of data sets were used by the model (Table 7).

Table 7. Datasets used during N-SPECT modeling.

Data Type	Data Description	Source
Topography	Digital Elevation model (30m)	USGS 2006
Land Cover	Describes vegetation types and land use	NOAA C-CAP (NOAA 2000)
Soil	Soil data and erosional characteristics	NRCS 2005, SSURGO (Soil Survey Geographic Database)
Rainfall Erosivity Factor (R-factor)	Potential for rainfall to cause soil detachment	NRCS 1995
Precipitation- Annual	Average annual rainfall	Annual: Rainfall Atlas of Hawai‘i (Giambelluca *et al.* 2011)
Precipitation- Storm Events	Storm event scenarios- (2yr/24hr, 10yr/1hr, 100yr/24hr)	NOAA Atlas 14 (Perica et al. 2011)
Rainy days	# of days per year that produce surface runoff	Estimated by Gaut (2009) using historic raingage data.
Pollution coefficients	Values representing the concentration of pollutant runoff from each land cover class	Default values provided by N-SPECT
K-Factor	Describes soil erodibility	N-SPECT obtains value from SSURGO soil data
Curve Number (CN)	Determines rainfall-runoff relationship	N-SPECT obtains value from Land Cover and Hydrologic Soil Type
Development areas	Polygons delineating development parcels	LUPAG See section 3.1

3.2.2 Topography and Land Cover Data

Elevation data for Hawaiʻi (10 m resolution) was obtained from United States Geological Survey (USGS 2006). The Waiʻulaʻula basin watershed boundary was generated in ArcInfo using the USGS DEM data. The original watershed delineation of the Waiʻulaʻula basin was then adjusted to remove the uppermost portion on Mauna Kea (see figure 5). This was done for two major reasons: 1) existence of a flood prevention reservoir which creates a physical hydrological barrier and 2) resource manager's advice that drainage from upper southeast corner does not connect with lower part of Waiʻulaʻula watershed (Gaut 2009). After resampling the DEM to 30m, watershed delineations within N-SPECT model were created by clipping the DEM clipped to the boundaries of the Waiʻulaʻula basin with the "subwatershed" size set to "medium".

Information on land cover was obtained from the Coastal Change Analysis Program (C-CAP) which was developed as a nationally standardized land cover assessment for coastal regions of the United States (NOAA 2000). These data were downloaded and clipped to the watershed.

3.2.3 Soils Data

Information on soils of the region was acquired through the NRCS/USDA Soil Survey Geographic (SSURGO) database (NRCS 2005). Of specific relevance to N-SPECT are the "K-factor" and "hydrological soil group" data for soil types in the Waiʻulaʻula watershed. N-SPECT utilizes these data to estimate soil erodibility and assign curve number values.

3.2.4 R-Factor

R-Factor maps for Hawaiʻi were created by the Natural Resources Conservation Service (1995). For purposes of this study, maps were geo-referenced, digitized, converted to points, interpolated using kriging, clipped to the watershed and converted to a raster file. Although no specific interpolation method is universally accepted for erosivity, kriging is often strongly recommended (Angulo-Martinez *et al.* 2009, Men *et al.* 2008).

3.2.5 Precipitation Data

Annual rainfall data were obtained from the recently updated "Rainfall Atlas of Hawaii" (Giambelluca *et al.* 2011). These maps represent the best estimates of the mean annual rainfall for the 30-yr base period 1978–2007. Data were downloaded and clipped to watershed.

Within N-SPECT, the annual rainfall scenario also requires an estimate for number of rainy days that produce surface runoff. This number determines if the annual rainfall is divided into a large number of small storms or a small number of more intense storms. Reducing the number of rainy days will result in significant changes to estimates of runoff. The model assumes that the number of raining days is constant across the watershed. Because this assumption is not met for the Waiʻulaʻula watershed, the contributing area of the watershed was divided into three subbasins on the basis of topography and precipitation (Figure 5).

The number of rainy days was derived from daily precipitation data from 38 USGS stations located in the vicinity of the Waiʻulaʻula watershed. In analyzing the daily data, one must use a rainfall threshold to discriminate between rainy and non-rainy days. Gaut (2009) analyzed the station data and determined that the most accurate N-SPECT simulations were obtained when a threshold of 0.5 inches was used. The number of rainy days can be a highly influential parameter, the watershed was divided into three subbasins

(based on precipitation) to help spatially distribute the amount of rainy days across the watershed. The number of raining days was 6 for the Kawaihae subbasin, 11 for the Waimea subbasin and 18 for the forest subbasin.

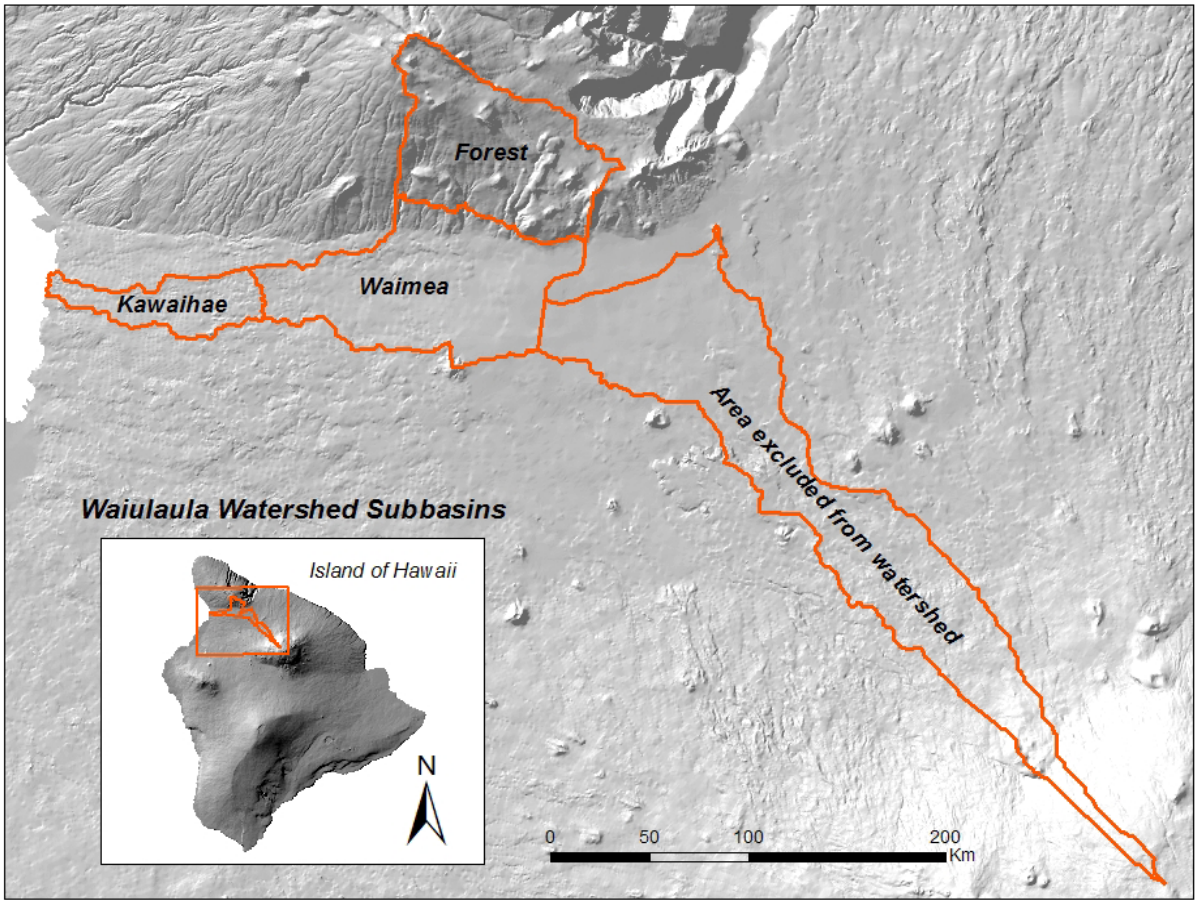


Figure 5. Wai'ula'ula watershed subbasins used during modeling.

Rainfall for design storms was acquired from the NOAA Precipitation Frequency Atlas 14 for the Hawaiian Islands (Perica *et al.* 2011). The storms used were the 10 year 1-hour; 2 year 24-hour; and 100 year 24-hour events. Precipitation data originally obtained as ASCII grids were converted to raster and re-sampled to 30m. N-SPECT does not require any estimate for number of rainy days when modeling the impact of a storm event. Instead, these are treated as singular discrete events.

3.2.6 Pollutant Coefficients (Average Concentrations)

Pollutant concentrations are expected to vary according to land cover type. For example, agricultural land would be expected to have higher nitrogen/phosphorus runoff than an equivalent area of forested land. Default values for the pollutant–land cover relationship have been established for the C-CAP land cover dataset. These values are derived from a national dataset of land cover pollutant runoff research

compiled by the Environmental Protection Agency (EPA). These pollutant coefficients are based on the event mean concentrations of pollutants in runoff coming from each land cover type. Due to the lack of locally available data the default pollutant coefficients were used in this analysis (Table 4).

3.3 Running the Model

Within the advanced settings of the N-SPECT model there are six different categories that can be manipulated: land cover types, pollutant concentrations , water quality standards (not used), precipitation scenarios, watershed delineations, and soils. For this study, default values for Land Cover (C-CAP) and pollutant concentrations were used. Precipitation Scenarios were created for each of the following: average annual, 10-year 1-hour storm; 2-year 24-hour storm and the 100-year 24-hour storm. The precipitation type, describing temporal distribution was set to "type 1" (all of Hawai'i is considered to be "type 1" (N-SPECT Users Manual). For the average annual precipitation scenario the amount of rainy days is also specified (see previous page). Soil data was setup for use within N-SPECT by pointing to the applicable locations for the DEM, "Hydrologic Soil Group" and "K factor", as well as fine-tuning the "A" and "B" constants in the MUSLE equation.

The models was run with "Local Effects Only" meaning that the output shows what is generated in each pixel. For each potential development site we modeled existing (pre-development) conditions using the existing C-CAP data. Post development conditions were modeled by changing the land use within the parcels to either low-development or high-development (depending on the LUPAG category). This is easily done by providing N-SPECT with polygons outlining the areas to be developed. The model was run for each of the different precipitation scenarios. The "Zonal statistics" GIS tool was used to extract output for each parcel. Differences between pre- and post- development represent the expected change in pollutants resulting from development.

4. Modeling Results

4.1 Direct Impacts Resulting from Full Build Out

Figures 6 to 9 show changes to runoff and pollutant loads resulting from development at full build out. In these figures, loads were divided by area to convert the data to yields (mass per hectare). Also shown are the percent change in load for each parcel (post development load minus pre-development load, divided by the pre-development load) and the change for each parcel as a percentage of the total load for the watershed. This latter value is a measure of the significance of the development's impact viewed from the perspective of the entire watershed. The appendices show results for all scenarios: average annual, design storms, and 50% build and 100% build out.

The two methods of estimating sediment loads give substantially different results. Generally, multiplication of runoff volumes by the assumed TSS concentration gave much higher sediment loads than did the RUSLE model. This was not true in the in the grassland areas in the southern part of the watershed, however, because little runoff was generated in this vegetation type. Of the two methods for estimating sediment loads, the RUSLE model is more realistic and grounded in science. For this reason, tables and figures in this report provide only the RUSLE/MUSLE results. RUSLE results reported herein include only that portion of the eroded sediment that is transported downstream. Sediment that was re-deposited within the watershed is not included. N-SPECT estimates that84% of sediment eroded in the in the Waiʻulaʻula watershed is transported downstream and 16% is re-deposited before reaching the ocean.

The change in runoff and pollutant loads vary according to whether average annual or design storms are considered (Figure 10). Runoff and nutrient loads are least for the 10-yr 1-hr storm and greatest for the average annual scenario. The 2-yr 24-hr storm produces more runoff and nutrient loads than the 10-yr 1-hr storm. The significance of these results is that if BMPs are designed to reduce loads for the 2-yr 24-hr event, they are likely to reduce loads and runoff for the 10-yr 1-hr event. Development decreases modeled erosion, so reverse trends observed for erosion, with the greatest decrease for the average annual scenario.

In evaluating the significance of impacts it is helpful to place them in the context of the entire 26 mi^2 watershed. The increased runoff resulting from development of all fourteen parcels is only a small percentage (about 9%) of the watershed's total runoff. Comparable figures for TP, TN, and sediment are about 23% and 13%, and 5% respectively. (Figures vary by precipitation scenario).

4.2 Two Levels of Development (50% and 100% Build Out)

New developments are typically built in stages, and as many as several decades may pass before construction is complete. Impacts at 50% build out are approximately half of what they are at full build out (Figure 11). They are not exactly half, however, because rainfall, soils, and topography vary across a proposed development parcel.

Figure 6. Predicted change in runoff depth (shown as colors) and volume (% changes) resulting from new development.

Values reflect full build out and the 2-year 24-hour design storm. Local change is the change for that parcel and watershed change is the change as a percentage of runoff for the entire watershed.

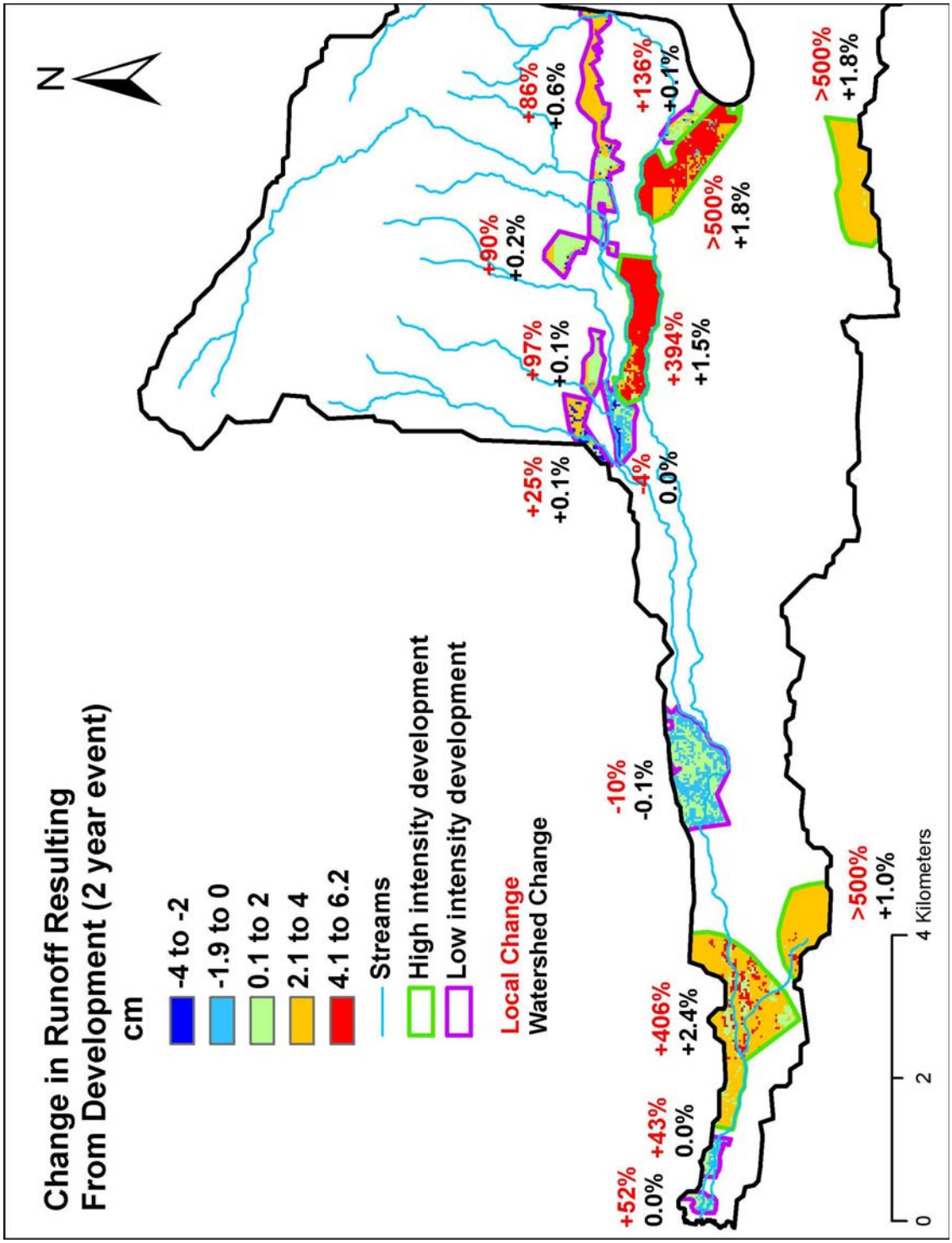


Figure 7. Predicted change in total nitrogen yield (shown as colors) and loads (% changes) resulting from new development.

Values reflect full build out and the 2-year 24-hour design storm. Local change is the change for that parcel and watershed change is the change as a percentage of runoff for the entire watershed.

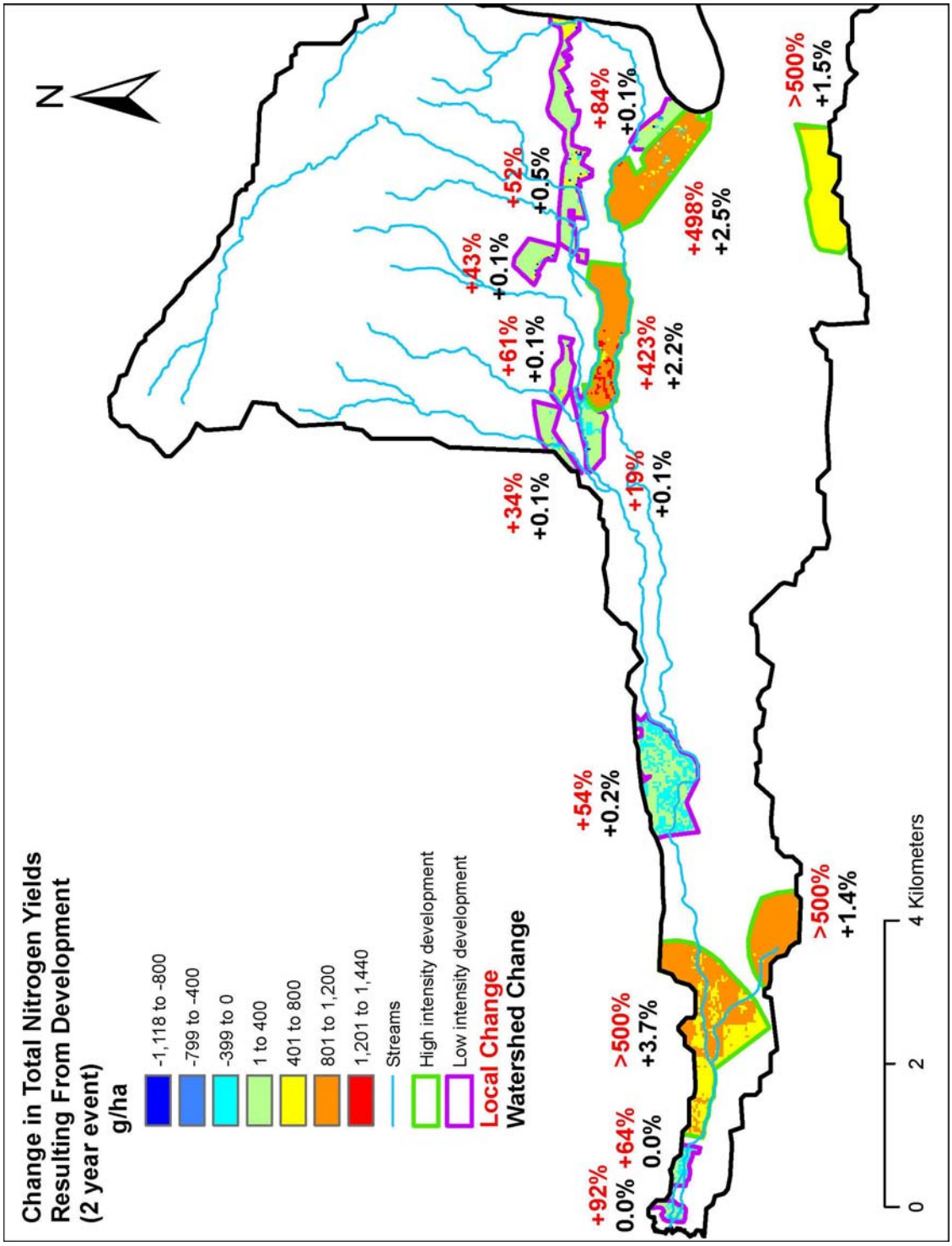


Figure 8. Predicted change in total phosphorus yield (shown as colors) and loads (% changes) resulting from new development.

Values reflect full build out and the 2-year 24-hour design storm. Local change is the change for that parcel and watershed change is the change as a percentage of runoff for the entire watershed.

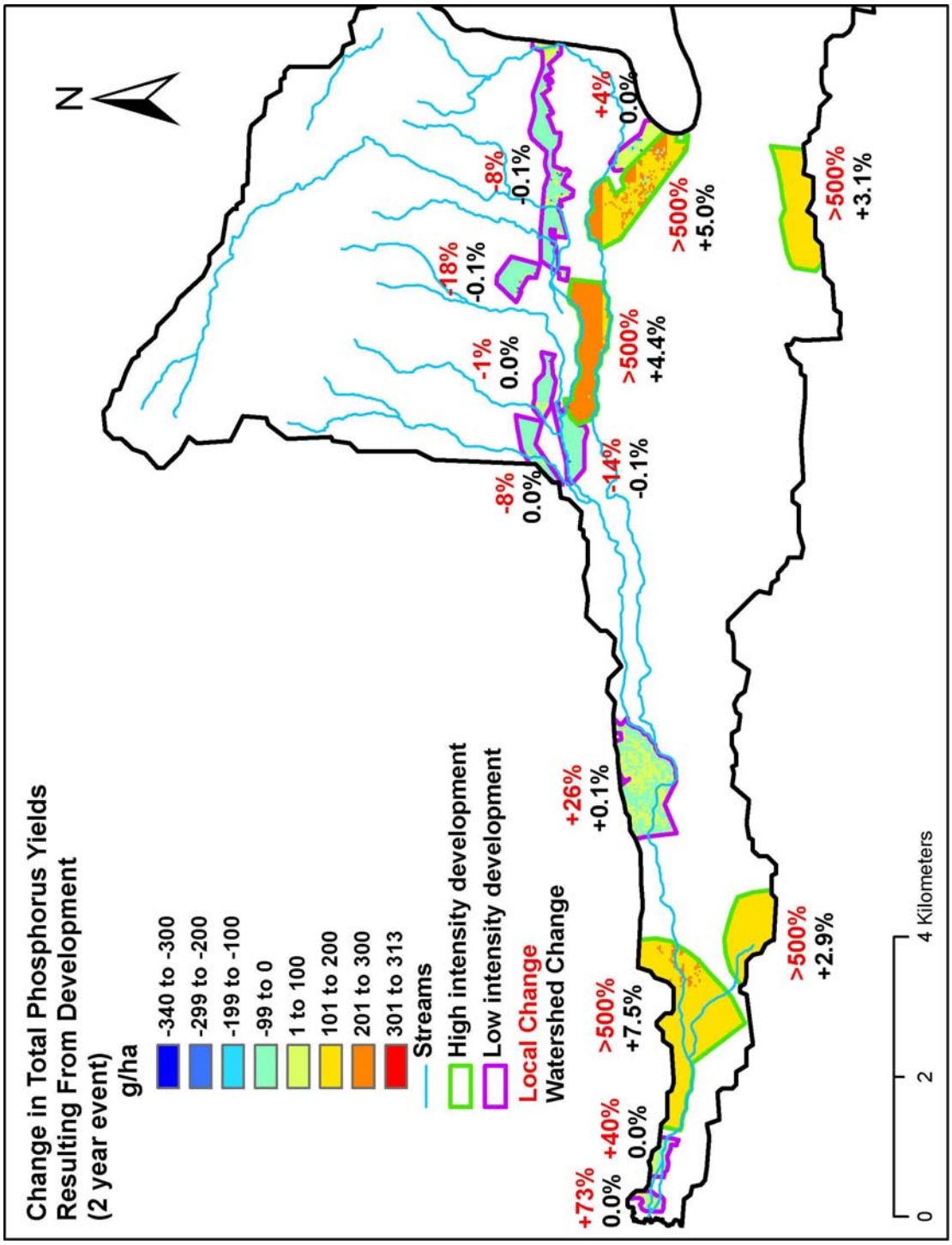


Figure 9. Change in average annual soil erosion shown as yields (colors) and loads (% changes), calculated using the RUSLE method.

Values do not include sediment that is eroded and re-deposited prior to leaving the watershed.

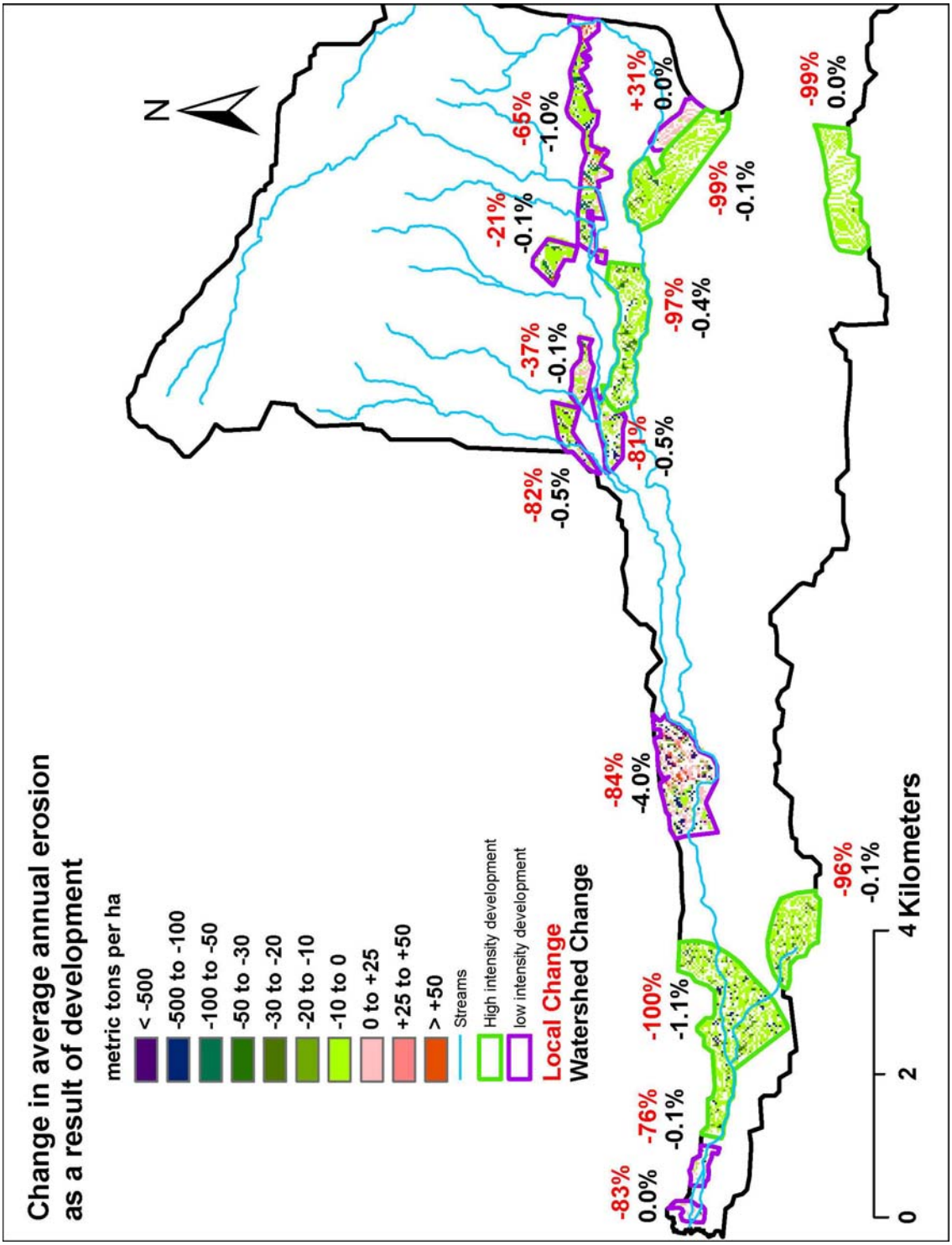


Figure 10. Change in load for different precipitation scenarios.

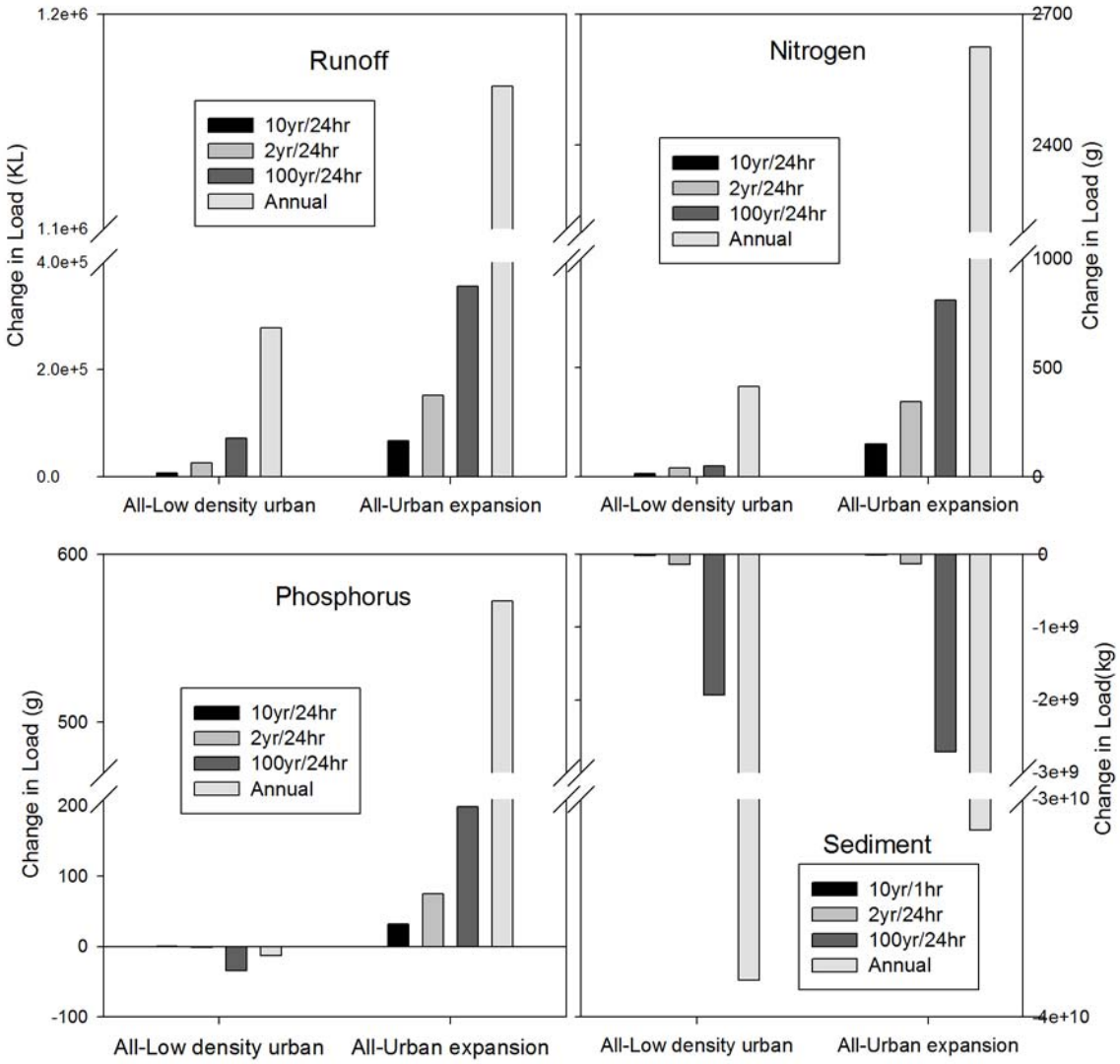
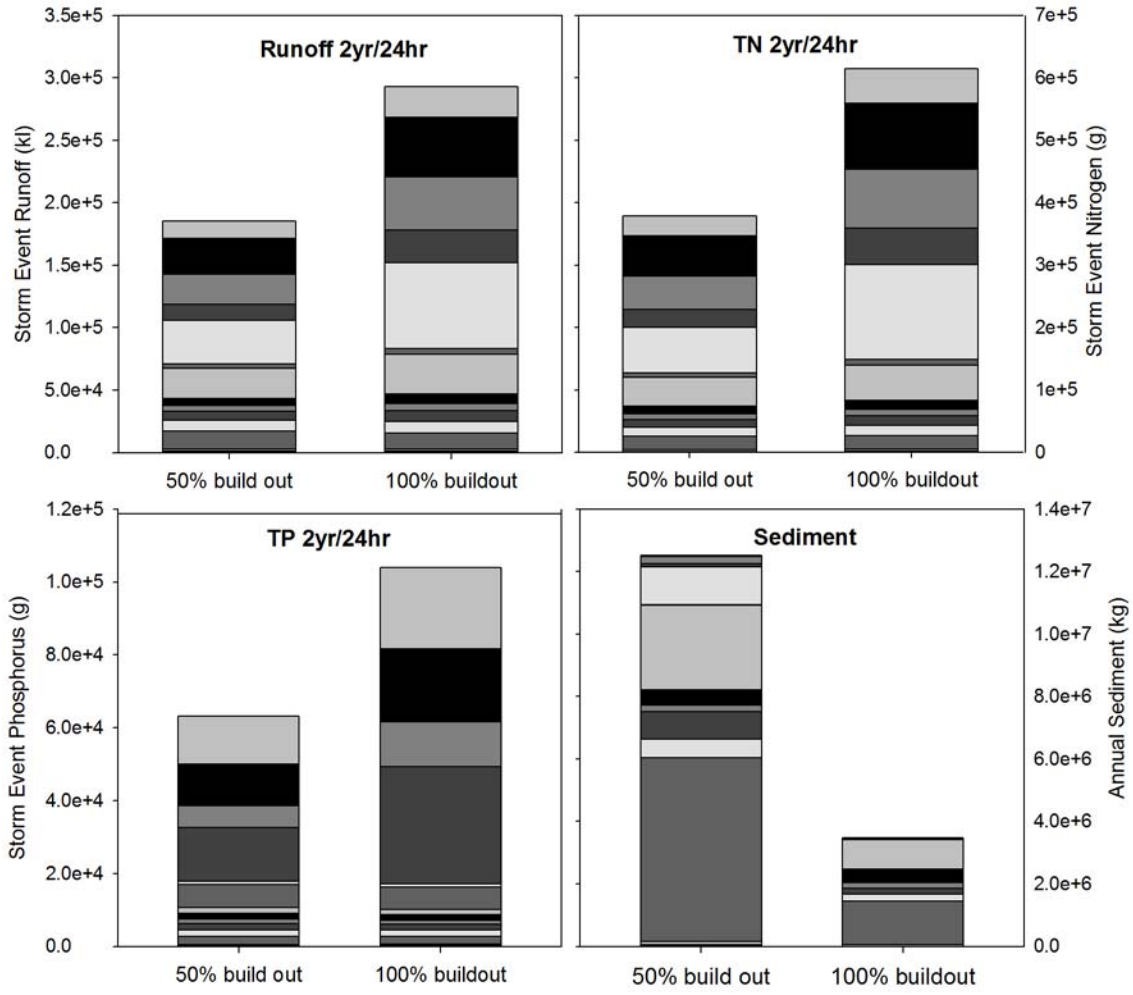


Figure 11. Runoff and pollutant loads at two levels of development (50% and 100% build out). Each bar contains 14 segments corresponding to each of the 14 parcels.



4.3 Cumulative Impacts

Runoff and loads were tabulated for three different categories of land (Table 8):

- Areas that are currently developed
- Areas that will be developed in the future (all the “proposed” developments)
- Remaining areas that are will never be developed under the LUPAG. These consist primarily of agricultural and conservation districts, including forest lands, grasslands, and very small amounts of cultivated land.

The combined effect of past and future development represents the cumulative impact of development. At full build out developed areas are predicted to contribute about 15%, 30%, 20%, and 5% of the entire watershed’s load of runoff, TP, TN, and sediment, respectively. (Numbers vary with precipitation scenario.) The "urban expansion" land use designation is expected to contribute a majority of the increase, with low density designations having less impact.

Notably, non-urbanized uses (mostly grassland and forest) are the greatest contributors to runoff and pollutant loads (Figure 12 and Table 8). This reflects the fact that the County General plan anticipates that most of the watershed will be remain undeveloped, with forest and grazing lands predominating. The high elevation forest receives by far the most precipitation and produces a large amount of runoff and associated nutrients and sediment. It is estimated that grasslands, which range from lush pasture to marginal scrub, contribute a majority of the phosphorus loads; both grasslands and forest are significant contributors to nitrogen loads.

Figure 12. Comparison of loads for existing development, future development, and other land use categories. The "parcels" are the future developments

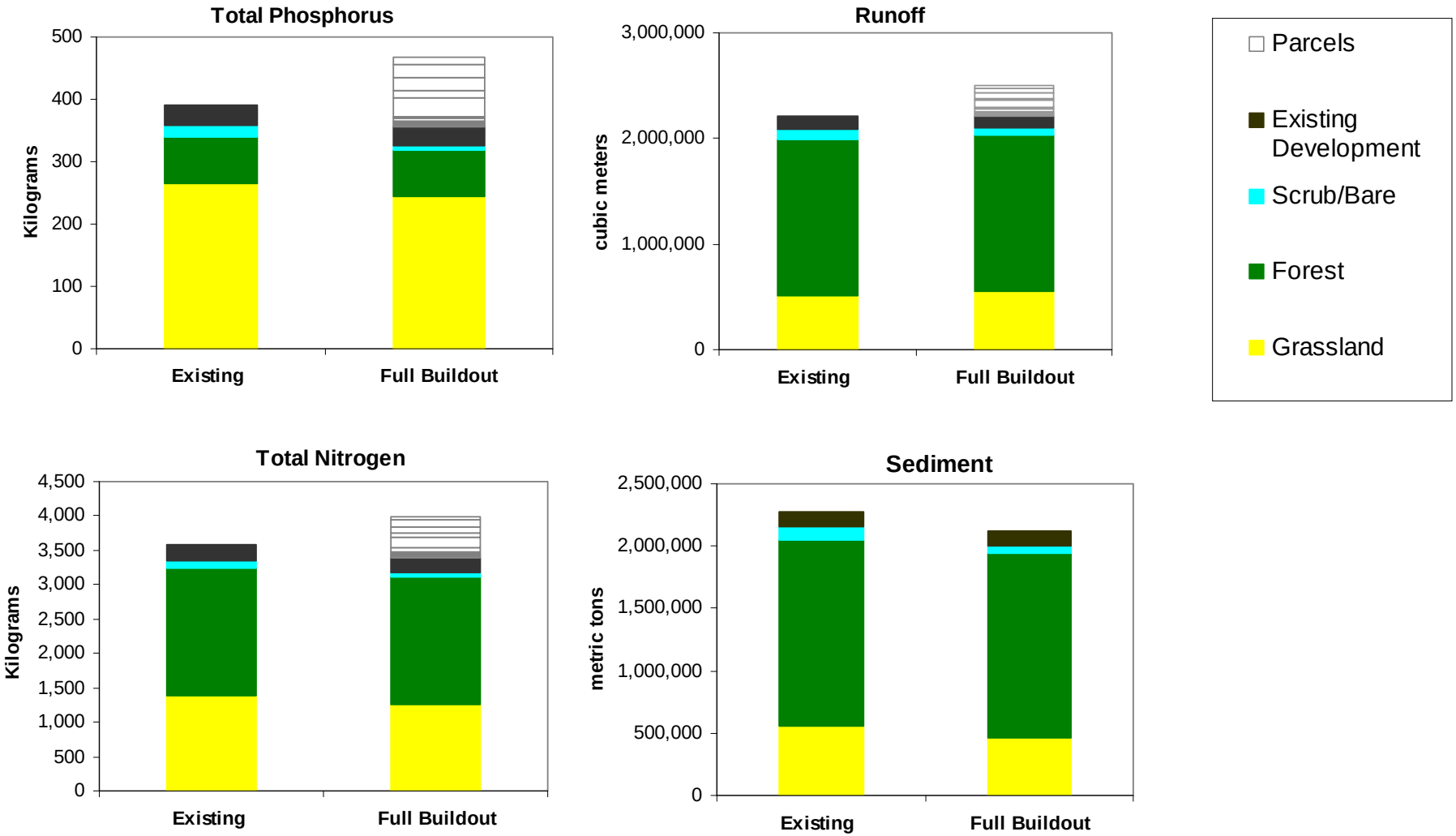


Table 8. Cumulative loads from existing and proposed development.

Results for runoff, phosphorus and nitrogen are for the 2-year 24-hr event. Sediment values are the average annual amount.

	Runoff (m^3)	Total Phosphorus (kg)	Total Nitrogen (kg)	Sediment delivered to watershed outlet (metric tons)
Proposed new developments				
Parcel 1	1,252	0.2	2.2	9.9
Parcel 2	1,680	0.3	3.0	44.2
Parcel 3	12,646	2.3	22.1	1383.5
Parcel 4	9,218	1.7	16.1	227.7
Parcel 5	8,598	1.6	15.4	190.3
Parcel 6	5,945	1.1	10.6	178.6
Parcel 7	7,667	1.5	13.9	441.9
Parcel 8	31,728	6.0	56.8	942.8
Parcel 9	4,777	0.9	8.5	20.2
Parcel 10	68,499	32.2	152.1	5.3
Parcel 11	26,205	12.3	58.2	8.5
Parcel 12	42,611	20.0	94.6	25.8
Parcel 13	47,415	22.3	105.3	2.7
Parcel 14	24,852	11.7	55.2	0.2
ALL future developments	**293,093**	**114**	**613.9**	**3,482**
Existing Development	**106,242**	**30**	**204.7**	**120,351**
Cumulative development	**399,335**	**144**	**819**	**123,833**
Other land uses				
Grassland	554,145	243.8	1268.2	464,117
Forest	1,480,757	74.0	1850.9	1,480,275
Scrub+Bare +cultivated	68,493	7.7	68.6	53,200
All non-urban	**2,103,395**	**326**	**3,188**	**1,997,593**
Watershed Total	**2,502,730**	**469**	**4,007**	**2,121,426**

4.4 Interpretation of Results

Proposed development in the Waiʻulaʻula watershed will be primarily in the form of low-density housing (low density urban, rural, and resort designations) and urban expansion, which is a more intense category of development. One parcel is slated for future industrial development. Potential industries might include a biofuels processing plant and auto repair shops.

According to the modeling study, the proposed developments will approximately triple runoff volume within the areas slated for future development. The increased runoff is a small percentage (5-10%) of the total runoff in the entire watershed, however. This is partly because it is a large watershed with a rain forest in the headwaters. Runoff is a nonlinear function of rainfall, so the amount of increased runoff varies according to the precipitation scenario being considered.[4] The amount of increased runoff also varies with the type of proposed development. For example, areas designated for urban expansion accounting are expected to increase runoff by a *factor* of 2-5 and account for about three-quarters of the increased runoff from all parcels. Areas designated for resort, rural, and low-density urban development are predicted to have much more modest increases in runoff (~45% increase). Several of the low-intensity parcels are expected to have decreased runoff for some precipitation scenarios.

According to the N-SPECT RUSLE model, the proposed developments will *reduce* average annual soil erosion to about 20% of pre-development values. Reductions are greatest for intense development (reduced to less than 10% of pre-development values for urban expansion and industrial parcels) and not as much for low intensity development (reduced to about 25% of predevelopment values for low density urban, rural, and resort parcels). The reductions make sense if one considers that soil cannot erode if it is covered by pavement or buildings. RUSLE assumes that raindrop impact is the process dislodging soil particles and causing erosion. Field measurements (see Volume 3) show significant suspended sediment in runoff from Waiʻulaʻula parking lots and roads, however. This suggests that other processes besides raindrop impact may be contributing to sediment in urban stormwater.

According to the assumptions made by the N-SPECT model, changes to nutrient *loads* result from both changes to runoff volume *and* changes to nutrient *concentrations* that arise from changes in land use. For total phosphorus (TP), loads will increase by a *factor* of 2-8 (depending on precipitation scenario) in the areas that are slated for high intensity development (urban expansion and industrial). The model predicts reductions or very small increases to TP loads in areas slated for low intensity development. Considering the combined impact of all proposed developments, the increase of unmitigated TP loads is only ~15% of the load for the entire watershed.

For total nitrogen (TN), loads will increase between 80% and a factor of 7 (depending on precipitation scenario) in the parcels that are slated for high intensity development. The model predicts smaller increases (20-50%) in areas slated for low intensity development. Considering the combined impact of all proposed developments, the increase of unmitigated TN loads is only about 8% of the load for the entire watershed.

If not mitigated, increased runoff can potentially cause downstream flooding, affect aquatic and riparian habitats, cause streambed or streambank erosion, and increase nutrient loads. Streamwaters

[4] High-intensity urban development will cause substantial increases in runoff for the 1-hour 10-year storm, which is used for drainage design in Hawaiʻi County but is not usually used in calculation of nutrient loads regulated under the Clean Water Act. Results from 1-hour 10-year storm are not discussed in the remainder of this section (4.4).

infiltrate into the channel bed in some of the streams in the watershed, at least some of the time. When streambed infiltration occurs, impacts on downstream ecosystems are reduced as a result of the loss of water itself and the loss dissolved nutrients within the water. Accordingly, one would expect that developments that are close to the ocean or sensitive riparian areas will have more impact than developments that are further away.

Development of the area designated for industry is expected to result in very substantial increases in runoff and nutrient loads. Because the future industrial parcel is almost two miles from the nearest stream, however, the impact on the aquatic and marine ecosystems will be limited, especially if standard mitigation measures are implemented.

This study examined results for the 2-year 24-hr storm, the 10-year 1-hr storm, the 100-year 24-hr storm and the average annual scenario. Although runoff and load numbers vary for each precipitation scenario, the overall picture is similar. Differences between precipitation scenarios could be important when designing mitigation structures, however. In some of the parcels a retention basin designed for a 1-hr 10-yr event could be six times too small during the 24-hr 100-yr storm.

Summary of Direct Impacts

Development of low-density housing is expected to increase runoff and in runoff and total nitrogen loads, with increases very approximately on the order of 40% increase. Low density housing is not expected to increase loads of total phosphorus. Exact values of increases vary according to the precipitation scenarios that are considered. High intensity development such as urban expansion or industrial facilities can be expected to cause very large increases in runoff and nutrient loads, with increases very approximately on the order of 4X within the boundaries of the proposed developments. All the increases are small, however, when viewed in the context of the entire, rather large, watershed. Expressed as a percentage increase within the boundaries of the proposed developments, stormwater impacts are large when the proposed development is for urban expansion or industry. The true ecological significance of the increased loads and runoff is difficult to assess, however, in the absence of loading goals for the watershed. The RUSLE model, which assumes that soil erosion is related to rainfall kinetic energy (not amount of runoff) and soil erodibility, predicts that development will decrease soil erosion. Soil cannot be eroded once it is paved over.

Cumulative Impacts and 50% Build Out

New developments are typically built in stages, and as many as several decades may pass before construction is complete. Impacts at 50% build out are approximately half of what they are at full build out (Appendix C). They are not exactly half, however, because rainfall, soils, and topography vary across a proposed development parcel.

At full build out the majority of the watershed will be undeveloped, with forest and grazing lands predominating. As a result, the developed portions of the watershed (sum of existing and planned) are expected to produce only 16% of the runoff for the entire watershed. Corresponding figures for phosphorus loads, nitrogen loads, and soil erosion are 30%, 20% and 1%, respectively. The "urban expansion" land use designation is expected to contribute a majority of the future load increases, with low density designations having far less impact.

5. Critique of Model

5.1 Discussion

N-SPECT is well-suited for predicting nutrient loads, runoff volumes, and erosion rates, both for proposed developments and for the entire watershed. This facilitates placing the proposed development in a larger context. Assuming that county General Plans describe anticipated future development, it is relatively straightforward to predict the cumulative impact of all past, proposed, and future development.

The model is also capable of predicting the concentration of pollutants in stormwater (either averaged over a storm event or in an average annual sense). Because pollutant concentrations are assumed to be constant for any land cover type, the predicted concentrations at the watershed outlet are only as accurate as the model parameters describing the concentration for each land cover type. While it would be easy to criticize the default concentration values as being too simplistic, it would be quite difficult to improve them. This is because field data vary considerably over time and there are few locations where runoff was derived from a single land cover type. Comprehensive measurements of pollutant concentrations are expensive and are lacking in many watersheds.

N-SPECT has two options for making sediment predictions. The first is to treat sediment the same as nutrients. In other words, to specify, for each land cover type, a fixed value for total suspended solids (TSS) concentration. Using this method, sediment loads are approximately proportional to runoff. The other method is to use RUSLE, which assumes that soil erosion is a function of soil erodibility, effects of vegetation and land management, the kinetic energy of raindrops, and topography. Of the two methods, we find RUSLE to be more credible.

N-SPECT is not designed to predict peak flows rates[5]. Unmitigated urbanization increases peak flow rates, which in turn have the potential to erode stream channels (thereby increasing loads to the coastal receiving waters) and degrade riparian and aquatic habitats. In most jurisdictions, mitigation measures must be specifically designed to prevent increases to peak flow. In most cases applicants applying for LEEDS certification must address impact on peak flow.

N-SPECT is not designed to evaluate the impacts of BMPs. One cannot use N-SPECT to see how much difference it makes if ipermeable pavement, buffer strips, and retention ponds are added to the design. This sharply limits its utility as a tool for designing mitigation measures or for demonstrating LEEDS compliance programs.

N-SPECT does not calculate pollutant loads to groundwater. This reflects the model's emphasis on surface water. In reality, however, urbanization results in infiltration of stormwaters containing dissolved nutrients and toxics such a pesticides and heavy metals. Groundwater so impaired can later flow into streams and wetlands as baseflow or flow into coastal receiving waters. While there are existing regulations that address protection of drinking water wells, regulations addressing ecological impacts of impaired groundwater are weak or absent. This is a particular concern along Hawaiian coastlines with reefs.

---

[5] Discharge has units of volume per time and represents the *rate* of runoff. Peak flow (peak discharge) is the maximum discharge during a runoff event. Runoff predictions made by N-SPECT are for volumes only.

With one exception ("R factor" rainfall erosivity), data needed for application of N-SPECT are readily and conveniently available in GIS format. NOAA's new online Precipitation Frequency Data Server (NOAA Atlas 14, Perica *et al.* 2011) makes it easy to obtain rainfall for design storms. Notably, federal and state guidelines recommend use of the 2-year 24-hour storm when estimating pollutant loads in a Clean Water Act context. For erosion, however, guidelines recommend calculation of average annual values. Fortunately, the N-SPECT sub-model for estimating runoff and pollutant loads was originally intended to be used for storm events and the N-SPECT sub-model for estimating erosion was originally intended to be used at the average annual time scale. While N-SPECT can easily calculate average annual runoff and pollutant loads, it must make several weak assumptions in order to do so.

N-SPECT is designed to be used with the C-CAP land cover (vegetation and land use) dataset. C-CAP has six vegetation categories and two urban categories. Because categories are broad, there can be variability within a category. For example, much of the Waiʻulaʻula watershed is classified as grassland. In terms of runoff and erosion potential, however, there is a substantial difference between the lush high-elevation grasslands, and the sparse semi-arid grasslands.

In the context of environmental assessment, the ultimate point of using N-SPECT is to evaluate the significance of changes to runoff and pollutant loads that are caused by land use changes. The model can inform us of likely changes to the amounts of runoff and pollutants. What it cannot tell us is whether or not these changes are significant. By and large, there is an absence of guidance for evaluating significance. The exception would be for watersheds with a Total Maximum Daily Load (TMDL) allocation. Because of the expense of conducting TMDL assessments, there are few watersheds with TMDLs. Of course, one can always compare predicted *stream* pollutant concentrations with State water quality standards. Making the comparison for marine receiving waters is much more complicated because further modeling would be needed to assess nutrient cycling and mixing of surface waters, marine waters, and groundwater discharge.

Currently, the N-SPECT model is free, but users must already have a license to the expensive ESRI ArcGIS software. Many analysts are already running ArcGIS, however, which is an industry standard. In the future, N-SPECT may be migrated away from ArcGIS because it is incompatible with the newer versions of ArcGIS. It is unclear how migration will affect ease of use. As of this writing, the most recent version of N-SPECT runs only on ArcGIS 9.1 or 9.2, but not on the most recent version of ArcGIS (version 10.x).

5.2 Strengths and Limitations

The principal strengths of the N-SPECT model are:

- Data needs are easily satisfied. With the exception of the "R factor" rainfall erosivity, GIS-ready input data is free and can be downloaded from online sources.

- It is relatively easy to model the proposed development, the entire watershed, and future land use change.[6] This allows the user to places the proposed development in a watershed context and predict cumulative loads.

[6] On Hawaiʻi Island the existence of the GIS version of the LUPAG map facilitates running cumulative scenarios (full build out). This may not be true for all islands.

- Default parameter values facilitate model application without time-consuming calibration or parameter estimation.

- GIS platform facilitates convenient processing of input and output data.

The principal limitations of the N-SPECT model are:

- No tools for predicting peak flow rate. This is a barrier to the use of the model by developers that are proposing mitigation measures to reduce stormwater impacts.

- No tools for modeling the impacts of BMPs.[7] This is a barrier to the use of the model by developers that are proposing mitigation measures to reduce stormwater impacts.

- C-CAP vegetation/land use categories can be too broad to accurately reflect variability across the watershed. This limitation is understandable but does limit the precision of model predictions.

- No tools for estimating secondary impacts to groundwater.

- No tools for estimating effects to stream channels (e.g. erosion and sedimentation).

- Pollutant coefficients (average concentration of a particular pollutant in runoff from a particular vegetation/land use type) may or may not be appropriate for the watershed. While users may supply their own custom values based on local measurements, there are few places in Hawaiʻi where measurements exist that can provide robust estimates of pollutant coefficients. Long-term autosampler measurement programs are needed and it is difficult to place the samplers in locations representing a single land use.

- There is no way to account for loss of runoff and pollutants in losing stream reaches.[8]

- As a GIS-based model, N-SPECT is easier to apply to large watersheds than many other models. It is not all that easy, however, and requires time and a certain level of expertise.[9]

---

[7] Although N-SPECT is not designed to evaluate BMPs, some types of BMPs can be modeled with N-SPECT. See Volume 3 for examples.

[8] Losing streams experience loss of water (and dissolved pollutants contained therein) as the result of streamwaters infiltrating into the streambed. When this occurs pollutants generated upstream may not reach the ocean. In the Waiʻulaʻula watershed many of the channels adjacent to and downstream of the "proposed" developments are losing reaches. Further note that It is possible for a section of channel to be "losing" during the dry season and "gaining" during the rainy season.

[9] As an example, when employing personnel with some skill in GIS and some background in hydrology it took about six person-months of manpower to conduct the modeling studies described in report. The time could probably be cut to two months using experts.

- The "raining days" parameter is problematic when the model is applied to large watersheds at the average annual time scale (Gaut 2009). Runoff is very sensitive to this parameter, which describes the number of runoff-producing rainstorms per year, and there is little if any guidance on how to choose values. N-SPECT's assumption that "raining days" is the same in every part of the watershed was clearly not true in the Wai'ula'ula watershed, which is admittedly unusual in that the climate ranges from arid to rainforest. More fundamentally, the raining days concept is an attempt to apply an event-based[10] runoff model to the prediction of average annual runoff. For this reason it may be better to apply the model to historic storms and design storms than to use it for average annual predictions. These comments apply to prediction of runoff and loads of nutrients. For prediction of soil erosion using the RUSLE model the situation is reversed. RUSLE as originally developed was intended to be applied at the average annual time scale.

- It is not clear if the calculations of the sediment delivery ratio (SDR) parameter are realistic.[11] N-SPECT predicted that in the 26 mi^2 Wai'ula'ula watershed only 14% of eroded soil was re-deposited before reaching the watershed outlet. This percentage seems too low (Bloom 2004).

5.3 Recommendations for Model Enhancements

Experience gained during the Pilot Study revealed several ways that N-SPECT could be enhanced. We recommend the following:

- Addition of capability for calculating peak flow rates.

- Addition of more categories of proposed development, in order to address the effects of commonly employed Best Management Practices. For example, instead of the current two development categories (high impact and low impact), there could be categories to represent high density urban developments with dry wells, or subdivisions employing LID strategies such as buffer strips and retention ponds.

- Development of default Curve Numbers, cover factors, and pollutant coefficients for GAP land categories. Developed by the U.S. Geological Survey (2011), GAP provides a detailed description of vegetation cover (28 categories) and anthropogenic land uses (six categories). Gaut (2009) has done preliminary work developing curve numbers and cover factors, but specification of pollutant coefficients remains problematic.

---

[10] An event-based hydrologic model is meant to be applied to one large rainstorm at a time. The alternative is a continuous model that must address baseflow and evaporation during the intervals between runoff-producing storms.

[11] The sediment delivery ratio is the ratio between the amount the sediment that is delivered by streams to the watershed outlet and the amount that is eroded from hillslopes. Field measurements show that surprisingly little of the soil that is eroded from hillslopes is actually delivered to watershed outlets. Presumably some of the eroded soil is being re-deposited somewhere along the way (Bloom 2004).

- If N-SPECT is applied at the average annual time scale then the raining days parameter is problematic (Gaut 2009). Runoff is very sensitive to this parameter, which describes the number of runoff-producing rainstorms per year, and there is little if any guidance about how to choose values. The model assumption that raining days is the same in every part of the watershed was clearly not true in the Waiʻulaʻula watershed, which is admittedly unusual in that the climate ranges from arid to rainforest. More fundamentally, the raining days concept is an attempt to apply an event-based[12] runoff model to the prediction of average annual runoff. For this reason it may be better to apply the model to historic storms and design storms than to use it for average annual predictions. These comments apply to prediction of runoff and loads of nutrients. For prediction of soil erosion using the RUSLE model the situation is reversed.

- Correcting the mislabeling of RUSLE output. Values are in g but the model labels it as mg.

- If users are less interested in soil erosion and more interested in sediment exports from the watershed, then evaluation of the sediment delivery ratio (SDR) parameter may be in order (Gaut 2009). In the Waiʻulaʻula watershed the SDR calculated by N-SPECT appears to be too high. It may be that the DEM topographic data used in the calculations were not at the appropriate resolution.

We also note that development of a GIS data layer representing R-factor maps for the State of Hawaiʻi would facilitate more widespread use of N-SPECT for calculating soil erosion.

[12] An event-based hydrologic model is meant to be applied to one large rainstorm at a time. The alternative is a continuous model that must address baseflow and evaporation during the intervals between runoff-producing storms.

6. References

Adamus C.L., M. Bergman. 1995. Estimating Nonpoint Source Pollution Loads with a GIS Screening Model. Water Resources Bulletin 31(4):647–655.

Angulo-Martinez M., M. Lopez-Vicente, S.M. Vicente-Serrano, S. Begueria. 2009. Mapping rainfall erosivity at a regional scale: a comparison of interpolation methods in the Ebro Basin (NE Spain). Hydrol. Earth Syst. Sci., 13, 1907-1920.

Bloom, A.L. 2004. Geomorphology: A Systematic Analysis of Late Cenozoic Landforms, 3rd ed. Waveland Press.

County of Hawaii. 2005. General Plan. Honolulu, Hawaii: Office of Planning: 14-7.

County of Hawaiʻi. 2005. Land Use Pattern Allocation Guide map for the island of Hawaiʻi as amended by Ordinance 06 153 (Bill 309, Draft 4). (Part of the County of Hawaiʻi General Plan)

Department of Geography and Environmental Studies at the University of Hawaiʻi and PBR-Hawaiʻi. 2011. Stormwater Impact Assessment Project: Final Report. Office of Planning, State of Hawaiʻi.

Environmental Protection Agency (US) [EPA}. 1983. Results of the Nationwide Urban Runoff Program (NURP): Volume 1 - Final Report. Washington (DC): Water Planning Division. p. 200.

Gaut, K. 2009. Application of the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) Model for Resource Management in the Waiʻulaʻula Watershed, Island of Hawaiʻi [thesis]. Hilo (HI): University of Hawaiʻi at Hilo. Available from ProQuest LLC, Ann Arbor, MI.

Giambelluca T.W., Q. Chen, A.G. Frazier, J.P. Price, Y-L Chen, P-S Chu, J. Eischeid, D. Delparte. 2011. The Rainfall Atlas of Hawaii. Available from http://rainfall.geography.hawaii.edu

Handbook for Stormwater Reclamation and Reuse Best Management Practices in Hawaii, Commission on Water Resource Management, State of Hawaii.

Mauna Kea Soil and Water Conservation District (MKSWCD). 2011. Waiʻulaʻula Watershed Management Plan. Marine and Coastal Solutions International Inc.

Men M., Y. Zhenrong, H Xu. 2008. Study on the spatial pattern of rainfall erosivity based on geostatistics in Hebei Province, China. Frontiers of Agriculture in China 2 (3):281-289.

National Oceanic and Atmospheric Agency (US) [NOAA] Coastal Services Center. 2000. Coastal Change Analysis Program (C-CAP). Available from http://www.csc.noaa.gov/ccap/pacific/ [accessed Dec 15, 2011]

National Oceanic and Atmospheric Agency (US) [NOAA] Coastal Services Center. 2004. Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) Technical Guide Version 1.0 Release 1. Charleston (SC): Coastal Services Center. p. 65. Available from http://www.csc.noaa.gov/digitalcoast/tools/nspect/support

National Oceanic and Atmospheric Agency (US) [NOAA] Coastal Services Center. 2009. Tutorial for the Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT), Author: Carter, J., Charleston (SC): Coastal Services Center. p. 42. Available from http://www.csc.noaa.gov/digitalcoast/tools/nspect/support

Natural Resources Conservation Services (US) [NRCS]. 1995. R-Factor Map of Hawaiʻi. Honolulu (HI): Hawaiʻi State Office.

Natural Resources Conservation Service (US) [NRCS]. 2005. Soil Survey Geographic (SSURGO) Database for Hawaiʻi County. Available at http://soildatamart.nrcs.usda.gov [accessed 12/1/2011].

Perica S., D. Martin, B. Lin, T. Parzybok, D. Riley, M. Yekta, L. Hiner, L.C. Chen, D. Brewer, F. Yan, K. Maitaria, C. Trypaluk, G. Bonnin. 2011. NOAA Atlas 14 Volume 4 Version 3, Precipitation-Frequency Atlas of the United States, Hawaiian Islands. NOAA, National Weather Service, Silver Spring, MD. Online data available at http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html

Renard K.G., G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder. 1997. Predicting soil erosion by water—a guide to conservation planning with the revised universal soil loss equation (RUSLE). Washington (DC): United States Department of Agriculture, Agricultural Research Service (USDA-ARS). Handbook No. 703.

Soil Conservation Service (US) [SCS]. 1986. Urban Hydrology for Small Watersheds. Technical Release 55, 2nd ed. Springfield (VA): USDA. p. 87-101.

Williams J.R. 1975. Sediment routing for agricultural watersheds. Water Resources Bulletin 11(5):965–974.

Williams J.R., H.D. Berndt. 1977. Sediment yield prediction based on watershed hydrology. Transactions of the American Society of Agricultural Engineers 20(6):1100-1104.

Wischmeier W.H., D.D. Smith. 1978. Predicting rainfall erosion losses: a guide to conservation planning, USDA Agriculture Handbook. Washington (DC): U.S. Government Printing Office. p.537.

APPENDIX A – Predicted Impacts for Average Annual Scenarios

Table A.1. Predicted change in annual average runoff at full build out.

Runoff change= runoff with development - runoff without development. Local % change= (100*change in runoff/original runoff). Watershed % change= (100*change in runoff/total runoff for watershed).

Parcel	Proposed Land Use	Intensity of Development	Runoff change (m^3/year)	Local change (%)	Watershed change (%)
1	Low density urban	Low	827	34	0.0
2	Resort	Low	482	17	0.0
3	Rural	Low	-29,789	-40	-0.1
4	Low density urban	Low	-4,172	-4	0.0
5	Low density urban	Low	18,531	26	0.1
6	Low density urban	Low	35,281	89	0.1
7	Low density urban	Low	45,962	76	0.2
8	Low density urban	Low	159,397	102	0.6
9	Low density urban	Low	21,274	167	0.1
10	Urban Expansion	High	259,408	520	0.9
11	Urban Expansion	High	110,405	1,031	0.4
12	Urban Expansion	High	392,293	362	1.4
13	Urban Expansion	High	404,448	591	1.4
14	Industrial	High	101,277	31,436	0.4
All low density urban			277,100	63	1.0
All resort node			482	17	0.0
All urban expansion			1,166,553	492	4.1
All rural			-29,789	-40	-0.1
All industrial			101,277	31,436	0.4
All high (10-14)			1,267,831	533	4.4
All low (1-9)			247,793	48	0.9
All parcels			1,515,624	201	5.3

Table A.2. Predicted change in annual average load of total nitrogen (TN) at full build out.

N change= TN with development – TN without development; Local change = (100*change in TN)/original TN; Watershed change = (100*change in TN)/(TN for entire watershed).

Parcel	Proposed Land use	Intensity of Development	N change (g/year)	Local % change	Watershed % change
1	Low density urban	Low	2,386	76	0.0
2	Resort	Low	1,745	41	0.0
3	Rural	Low	36,774	48	0.1
4	Low density urban	low	26,025	19	0.1
5	Low density urban	low	41,198	35	0.1
6	Low density urban	low	46,438	53	0.1
7	Low density urban	low	46,818	32	0.1
8	Low density urban	low	219,271	64	0.5
9	Low density urban	low	31,720	110	0.1
10	Urban Expansion	high	612,547	829	1.4
11	Urban Expansion	high	243,454	953	0.6
12	Urban Expansion	high	880,550	381	2.0
13	Urban Expansion	high	887,611	547	2.1
14	Industrial	high	225,069	46,667	0.5
All low density urban			413,856	48	1.0
All resort node			1,745	41	0.0
All urban expansion			2,624,162	532	6.1
All rural			36,774	48	0.1
All industrial			225,069	46,667	0.5
All high (10-14)			2,849,231	577	6.6
All low (1-9)			452,374	48	1.0
All parcels			3,301,605	230	7.6

Table A.3. Predicted change in annual average load of total phosphorus (TP) at full build out.
P change= TP with development – TP without development; Local % change= (100*change in TP)/(original TP). Watershed % change= (100* change in TP)/(TP for entire watershed).

Parcel	Proposed Land use	Intensity of Development	P change (g/year)	Local change (%)	Watershed change (%)
1	Low density urban	low	214	61	0.0
2	Resort	low	134	28	0.0
3	Rural	low	2,080	22	0.1
4	Low density urban	low	-2,552	-13	-0.1
5	Low density urban	low	-1,539	-8	0.0
6	Low density urban	low	-969	-6	0.0
7	Low density urban	low	-6,904	-25	-0.2
8	Low density urban	low	-1,624	-3	0.0
9	Low density urban	low	951	18	0.0
10	Urban Expansion	high	133,765	1,159	3.3
11	Urban Expansion	high	52,029	1,062	1.3
12	Urban Expansion	high	194,688	481	4.7
13	Urban Expansion	high	191,618	627	4.7
14	Industrial	high	47,666	55,444	1.2
All low density urban			-12,423	0	0.0
All resort node			134	28	0.0
All urban expansion			572,100	510	7.1
All rural			2,080	41	0.1
All industrial			47,666	216	1.4
All high (10-14)			619,766	708	15.1
All low (1-9)			-10,209	-7	-0.2
All parcels			609,557	250	14.8

Table A.4. Predicted change in average annual soil erosion sediment load at full build out, according to the RUSLE model.

Sediment change= erosion with development – erosion without development; local % change= (100*change in erosion)/(original erosion); Watershed % change= (100*change in erosion)/ (total erosion for the entire watershed). Sediment that is re-deposited prior to leaving the watershed is not included.

Parcel	Proposed Land use	Intensity of Development	Sediment change (kg/year)	Local change (%)	Watershed change (%)
1	Low density urban	low	-46,908	-83	0.0
2	Resort	low	-138,312	-76	-0.1
3	Rural	low	-7,321,510	-84	-4.0
4	Low density urban	low	-942,288	-81	-0.5
5	Low density urban	low	-859,383	-82	-0.5
6	Low density urban	low	-103,854	-37	-0.1
7	Low density urban	low	-117,865	-21	-0.1
8	Low density urban	low	-1,764,854	-65	-1.0
9	Low density urban	low	4,802	31	0.0
10	Urban Expansion	high	-1,977,224	-100	-1.1
11	Urban Expansion	high	-198,818	-96	-0.1
12	Urban Expansion	high	-776,991	-97	-0.4
13	Urban Expansion	high	-190,421	-99	-0.1
14	Industrial	high	-25,696	-99	0.0
All low density urban			-3,830,349	-79	-5.2
All resort			-138,312	-76	-0.1
All urban expansion			-3,143,453	-92	-1.7
All rural			-7,321,510	-75	-0.8
All industrial			-25,696	-99	0.0
All low (1-9)			-11,290,171	-77	-6.1
All high (10-14)			-3,169,150	-99	-1.7
All low + All high			-14,459,321	-81	-7.8

APPENDIX B – Predicted impacts for

Design Storm Scenarios

Table B.1. Predicted change to runoff for design storms and full build out.

Runoff change= runoff with development - runoff without development. Local % change= (100*change in runoff)/(original runoff). Watershed % change= (100*change in runoff)/(total runoff for Watershed).

Precipitation Scenarios	10-year 1-hour Storm Event			2-year 24-hour Storm Event			100-year 24-hour Storm Event		
Parcel-proposed land use	**Runoff change (m^3/year)**	**Local change (%)**	**Watershed change (%)**	**Runoff change (m^3/year)**	**Local change (%)**	**Watershed change (%)**	**Runoff change (m^3/year)**	**Local change (%)**	**Watershed change (%)**
1-Low density urban	10	6	0.0	431	52	0.0	2,529	35	0.0
2-Resort	26	13	0.0	509	43	0.0	2,617	25	0.0
3-Rural	-1,818	-56	-0.4	-1,393	-10	-0.1	18,936	21	0.2
4-Low density urban	-628	-26	-0.1	-373	-4	0.0	1,387	3	0.0
5- Low density urban	348	27	0.1	1,728	25	0.1	5,005	12	0.0
6- Low density urban	842	285	0.2	2,931	97	0.1	7,970	31	0.1
7- Low density urban	1,129	299	0.2	3,640	90	0.2	9,184	28	0.1
8- Low density urban	4,615	220	1.0	14,639	86	0.6	36,447	28	0.3
9- Low density urban	684	245	0.1	2,749	136	0.1	9,063	40	0.1
10-Urban expansion	22,898	1,040	4.7	54,959	406	2.4	132,609	93	1.2
11-Urban expansion	9,632	20,333	2.0	23,122	750	1.0	55,255	109	0.5
12-Urban expansion	15,652	1,742	3.2	33,988	394	1.5	74,232	83	0.7
13-Urban expansion	18,579	2,442	3.8	39,919	533	1.8	93,099	99	0.8
14-Industrial	8,990	33,542	1.9	24,730	20,269	1.1	96,745	513	0.9
All-Low density urban	7,001	101	1.4	25,745	59	1.1	71,584	23	0.6
All- Resort	26	13	0.0	509	43	0.0	2,617	25	0.0
All-Urban expansion	66,761	1,708	13.8	151,989	464	6.7	355,195	94	3.1
All-Rural	-1,818	-56	-0.4	-1,393	-10	-0.1	18,936	21	0.2
All-Industrial	8,990	33,542	1.9	24,730	20,269	1.1	96,745	513	0.9
All Low (1-9)	5,208	50	1.1	24,862	42	1.1	93,137	23	0.8
All High (10-14)	75,751	1,322	15.7	176,719	353	7.8	451,939	79	4.0
All Parcels	80,959	565	16.7	201,580	220	8.9	545,076	68	4.8

Table B.2. Predicted change to total phosphorus (TP) loads for design storms and full build out.

P change= TP with development – TP without development. Local % change= (100*change in TP)/(original TP). Watershed % change= (100*change in TP)/(TP for entire Watershed).

Precipitation Scenarios	10-year 1 hour Storm Event			2-year 24-hour Storm Event			100-year 24-hour Storm Event		
Parcel-proposed land use	**P change (g/year)**	**Local change (%)**	**Watershed change (%)**	**P change (g/year)**	**Local change (%)**	**Watershed change (%)**	**P change (g/year)**	**Local change (%)**	**Watershed change (%)**
1-Low density urban	8	33	0.0	93	73	0.0	658	63	0.0
2-Resort	12	39	0.0	87	40	0.0	205	9	0.0
3-Rural	-140	-35	-0.2	471	26	0.1	8,289	72	0.3
4-Low density urban	-104	-25	-0.2	-267	-14	-0.1	-2,114	-18	-0.1
5- Low density urban	76	34	0.1	-147	-8	0.0	-3,569	-29	-0.1
6- Low density urban	120	140	0.2	-8	-1	0.0	-3,415	-35	-0.1
7- Low density urban	108	63	0.2	-342	-18	-0.1	-6,208	-42	-0.2
8- Low density urban	437	53	0.7	-500	-8	-0.1	-16,657	-34	-0.6
9- Low density urban	60	50	0.1	31	4	0.0	-2,705	-32	-0.1
10-Urban expansion	11,519	4,194	18.0	28,679	818	7.5	81,629	172	3.2
11-Urban expansion	4,544	79,814	7.1	10,898	768	2.9	26,116	110	1.0
12-Urban expansion	7,566	3,577	11.8	16,900	542	4.4	42,319	123	1.6
13-Urban expansion	8,777	2,802	13.7	19,002	580	5.0	48,560	125	1.9
14-Industrial	4,230	58,250	6.6	11,654	43,814	3.1	45,592	522	1.8
All-Low density urban	706	38	1.1	-1,139	-8	-0.3	-34,009	-32	-1.3
All- Resort	12	39	0.0	87	40	0.0	205	9	0.0
All-Urban expansion	32,405	4,025	50.6	75,480	667	19.8	198,623	137	7.7
All-Rural	-140	-35	-0.2	471	26	0.1	8,289	72	0.3
All-Industrial	4,230	58,250	6.6	11,654	43,814	3.1	45,592	522	1.8
All Low (1-9)	578	25	0.9	-580	-4	-0.2	-25,515	-21	-1.0
All High (10-14)	36,636	2,966	57.2	87,133	496	22.8	244,215	110	9.5
All Parcels	37,213	1,197	58.1	86,553	315	22.7	218,700	80	8.5

Table B.3. Predicted change to total nitrogen (TN) loads for design storms and full build out.

N change= TN with development – TN without development. Local % change= (100*change in TN)/(original TN). Watershed % change= (100*change in TN)/(TN for entire Watershed).

Precipitation Scenarios	10-year 1 hour Storm Event			2-year 24-hour Storm Event			100-year 24-hour Storm Event		
Parcel-proposed land use	**N change (g/year)**	**Local % change**	**Watershed change (%)**	**N change (g/year)**	**Local % change**	**Watershed change (%)**	**N change (g/year)**	**Local % change**	**Watershed change (%)**
1-Low density urban	97	48	0.0	1,032	92	0.0	6,476	63	0.0
2-Resort	138	52	0.0	1,165	64	0.0	5,663	32	0.0
3-Rural	-719	-22	-0.1	7,755	54	0.2	93,154	92	0.5
4-Low density urban	48	2	0.0	2,598	19	0.1	12,759	16	0.1
5- Low density urban	1,227	72	0.2	3,915	34	0.1	6,140	8	0.0
6- Low density urban	1,441	250	0.2	4,028	61	0.1	3,436	6	0.0
7- Low density urban	1,803	204	0.3	4,176	43	0.1	-1,833	-2	0.0
8- Low density urban	7,437	163	1.1	19,486	52	0.5	16,230	6	0.1
9- Low density urban	1,100	179	0.2	3,884	84	0.1	6,915	14	0.0
10-Urban expansion	53,437	2,350	7.6	130,288	599	3.7	332,519	120	1.7
11-Urban expansion	21,443	46,629	3.0	50,810	687	1.4	112,134	91	0.6
12-Urban expansion	35,291	2,434	5.0	76,559	423	2.2	167,438	85	0.8
13-Urban expansion	41,260	2,462	5.8	87,662	498	2.5	198,880	92	1.0
14-Industrial	19,976	49,359	2.8	55,001	32,318	1.5	211,051	463	1.1
All-Low density urban	13,152	114	1.9	39,118	46	1.1	50,123	8	0.3
All- Resort	138	52	0.0	1,165	64	0.0	5,663	32	0.0
All-Urban expansion	151,431	2,781	21.4	345,319	533	9.7	810,971	100	4.1
All-Rural	-719	-22	-0.1	7,755	54	0.2	93,154	92	0.5
All-Industrial	19,976	49,359	2.8	55,001	32,318	1.5	211,051	463	1.1
All Low (1-9)	12,572	84	1.8	48,039	48	1.4	148,940	20	0.8
All High (10-14)	171,406	2,044	24.2	400,320	396	11.3	1,022,022	82	5.2
All Parcels	183,978	896	26.0	448,359	271	12.6	1,170,962	73	5.9

Table B.4. Predicted change to MUSLE erosion for design storms and full build out.

Sediment change= erosion with development – erosion without development). Local % change= (100*change in erosion)/(original erosion). Watershed % change= (100*change in erosion)/(total erosion for entire watershed). Sediment that is re-deposited prior to leaving the watershed is not included.

Precipitation Scenarios	10-year-1-hour Storm Event			2-year 24-hour Storm Event			100-year 24-hour Storm Event		
Parcel-proposed land use	Sediment change (kg/year)	Local change (%)	Watershed change (%)	Sediment change (kg/year)	Local change (%)	Watershed change (%)	Sediment change (kg/year)	Local change (%)	Watershed change (%)
1-Low density urban	-24	-99	-0.1	-283	-96	0.0	-5,171	-90	0.0
2-Resort	-74	-99	-0.2	-856	-94	-0.1	-15,406	-84	-0.1
3-Rural	-1,707	-97	-4.1	-35,646	-93	-4.5	-857,424	-89	-5.5
4-Low density urban	-1,235	-90	-2.9	-10,783	-87	-1.4	-138,452	-84	-0.9
5- Low density urban	-1,354	-98	-3.2	-11,780	-92	-1.5	-130,919	-86	-0.8
6- Low density urban	-80	-85	-0.2	-410	-42	-0.1	-5,934	-29	0.0
7- Low density urban	32	3,363	0.1	862	227	0.1	5,176	21	0.0
8- Low density urban	508	1,211	1.2	8,638	321	1.1	81,362	62	0.5
9- Low density urban	0	139	0.0	22	248	0.0	340	47	0.0
10-Urban expansion	-772	-100	-1.8	-9,054	-100	-1.1	-181,213	-100	-1.2
11-Urban expansion	-1	-100	0.0	-17	-97	0.0	-7,932	-96	-0.1
12-Urban expansion	-481	-100	-1.1	-4,356	-100	-0.5	-75,594	-99	-0.5
13-Urban expansion	0	-99	0.0	-27	-96	0.0	-6,488	-98	0.0
14-Industrial	0	-100	0.0	-7	-100	0.0	-731	-99	0.0
All-Low density urban	-2,152	-74	-5.1	-13,734	-47	-1.7	-193,598	-39	-1.2
All- Resort	-74	-99	-0.2	-856	-94	-0.1	-15,406	-84	-0.1
All-Urban expansion	-1,253	-100	-3.0	-13,454	-100	-1.7	-271,227	-99	-1.7
All-Rural	-1,707	-97	-4.1	-35,646	-93	-4.5	-857,424	-89	-5.5
All-Industrial	0	-100	0.0	-7	-100	0.0	-731	-99	0.0
All Low (1-9)	-3,933	-83	-9.3	-50,237	-73	-6.3	-1,066,428	-72	-6.8
All High (10-14)	-1,254	-57	-3.0	-13,461	-61	-1.7	-271,959	-64	-1.7
All Low + All High	-5,187	-87	-12.3	-63,698	-77	-8.0	-1,338,386	-76	-8.5

APPENDIX C: Two Development Levels

(50% and 100% Build Out)

Table C.1. Predicted change to 2-yr 24-hr runoff for 100% and 50% build out.

Parcel	Size (acres)	Existing land use	Type of proposed development	Pre-development runoff m^3	Runoff after 50% buildout m^3	Runoff after 100% buildout m^3	Δ Runoff resulting from 50% buildout (%)	Δ Runoff resulting from 100 % buildout (%)	ratio of 50% impact to 100% impact (dimensionless)
1	23.4	Scrub/Shrub	low density urban	821	1,106	1,252	26%	52%	0.66
2	31.9	Low intensity developed	low density urban	1,171	1,606	1,680	27%	43%	0.85
3	249.2	Scrub/Shrub/Bare Land	low density urban	14,039	14,291	12,646	2%	-10%	-0.18
4	73.0	Bare Land	low density urban	9,592	8,755	9,218	-10%	-4%	2.24
5	56.4	Grassland	low density urban	6,869	7,166	8,598	4%	25%	0.17
6	46.2	Grassland	low density urban	3,014	4,598	5,945	34%	97%	0.54
7	53.8	Grassland	low density urban	4,028	5,970	7,667	33%	90%	0.53
8	204.2	Grassland	resort node	17,089	23,758	31,728	28%	86%	0.46
9	55.2	Grassland	rural	2,028	3,632	4,777	44%	136%	0.58
10	418.8	Grassland	urban expansion	13,539	35,099	68,499	61%	406%	0.39
11	159.0	Grassland	urban expansion	3,083	12,701	26,205	76%	750%	0.42
12	199.8	Grassland	urban expansion	8,624	24,016	42,611	64%	394%	0.45
13	246.1	Grassland	urban expansion	7,496	28,865	47,415	74%	533%	0.54
14	191.9	Grassland	industrial	122	13,956	24,852	99%	20,270%	0.56
All	2009.0			91,513	185,519	293,093	51%	220%	0.47

Table C.2. Predicted change to 2-yr 24-hr Total Phosphorus (TP) loads for 100% and 50% build out.

Parcel	Size	Existing land use	Type of proposed development	Pre-development TP (g)	TP after 50% buildout (g)	TP after 100% buildout (g)	Δ TP resulting from 50% buildout (%)	Δ TP resulting from 100 % buildout (%)	Ratio of 50% impact to 100% impact (dimensionless)
1	23.4	Scrub/Shrub	low density urban	127	184	221	31%	73%	0.61
2	31.9	Low intensity developed	low density urban	217	289	305	25%	40%	0.82
3	249.2	Scrub/Shrub Bare Land	low density urban	1,787	2,282	2,258	22%	26%	1.05
4	73.0	Bare Land	low density urban	1,919	1,675	1,652	-15%	-14%	0.91
5	56.4	Grassland	low density urban	1,765	1,792	1,618	2%	-8%	-0.18
6	46.2	Grassland	low density urban	1,118	1,190	1,111	6%	-1%	-10.
7	53.8	Grassland	low density urban	1,850	1,626	1,508	-14%	-18%	0.65
8	204.2	Grassland	resort node	6,537	6,232	6,037	-5%	-8%	0.61
9	55.2	Grassland	rural	854	923	885	7%	4%	2.23
10	418.8	Grassland	urban expansion	3,504	14,821	32,184	76%	818%	0.39
11	159.0	Grassland	urban expansion	1,419	5,978	12,317	76%	768%	0.42
12	199.8	Grassland	urban expansion	3,118	11,305	20,018	72%	542%	0.48
13	246.1	Grassland	urban expansion	3,276	13,364	22,278	75%	580%	0.53
14	191.9	Grassland	industrial	27	6,549	11,680	100%	44,000%	0.56
All	2009.0			27,519	68,210	114,072	60%	315%	0.47

Table C.3. Predicted change to 2-yr 24-hr Total Nitrogen (TN) loads for 100% and 50% build out.

Parcel	Size (acres)	Existing land use	Type of proposed development	Pre-development TN (g)	TN after 50% buildout (g)	TN after 100% buildout (g)	Δ TN resulting from 50% buildout (%)	Δ TN resulting from 100 % buildout (%)	Ratio of 50% impact to 100% impact (dimensionless)
1	23.4	Scrub/Shrub	low density urban	1,122	1,690	2,154	34%	92%	0.55
2	31.9	Low intensity developed	low density urban	1,814	2,639	2,979	31%	64%	0.71
3	249.2	Scrub/Shrub Bare Land	low density urban	14,333	21,329	22,088	33%	54%	0.90
4	73.0	Bare Land	low density urban	13,501	14,408	16,099	6%	19%	0.35
5	56.4	Grassland	low density urban	11,480	13,056	15,395	12%	34%	0.40
6	46.2	Grassland	low density urban	6,591	9,014	10,618	27%	61%	0.60
7	53.8	Grassland	low density urban	9,696	11,867	13,872	18%	43%	0.52
8	204.2	Grassland	resort node	37,350	46,033	56,836	19%	52%	0.45
9	55.2	Grassland	rural	4,616	6,989	8,500	34%	84%	0.61
10	418.8	Grassland	urban expansion	21,763	72,914	152,051	70%	599%	0.39
11	159.0	Grassland	urban expansion	7,393	28,634	58,203	74%	687%	0.42
12	199.8	Grassland	urban expansion	18,081	54,225	94,640	67%	423%	0.47
13	246.1	Grassland	urban expansion	17,602	64,351	105,264	73%	498%	0.53
14	191.9	Grassland	Industrial	170	30,956	55,172	99%	32318%	0.56
All	2009.0			165,512	378,106	613,871	56%	271%	0.47

Table C.4. Predicted change to Annual RUSLE erosion for 100% and 50% build out.

Parcel	Size (acres)	Existing land use	Type of proposed development	Pre-development Sediment (kg)	Sediment after 50% buildout (kg)	Sediment after 100% buildout (kg)	Δ Sediment resulting from 50% buildout (%)	Δ Sediment resulting from 100% buildout (%)	Ratio of 50% impact to 100% impact (dimensionless)
1	23.4	Scrub/Shrub	low density urban	56,853	52,887	9,945	-7%	-83%	0.08
2	31.9	Low intensity developed	low density urban	182,502	91,979	44,190	-98%	-76%	0.65
3	249.2	Scrub/Shrub Bare Land	low density urban	8,704,990	5,893,253	1,383,480	-48%	-84%	0.38
4	73.0	Bare Land	low density urban	1,169,960	586,840	227,672	-99%	-81%	0.62
5	56.4	Grassland	low density urban	1,049,700	897,185	190,317	-17%	-82%	0.18
6	46.2	Grassland	low density urban	282,477	195,108	178,623	-45%	-37%	0.84
7	53.8	Grassland	low density urban	559,769	502,386	441,904	-11%	-21%	0.49
8	204.2	Grassland	resort node	2,707,684	2,692,905	942,830	-1%	-65%	0.01
9	55.2	Grassland	rural	15,415	18,330	20,218	16%	31%	0.61
10	418.8	Grassland	urban expansion	1,982,550	1,219,388	5,326	-63%	-100%	0.39
11	159.0	Grassland	urban expansion	207,313	110,103	8,495	-88%	-96%	0.49
12	199.8	Grassland	urban expansion	802,791	213,829	25,800	-275%	-97%	0.76
13	246.1	Grassland	Urban expansion	193,162	30,900	2,741	-525%	-99%	0.85
14	191.9	Grassland	industrial	25,881	11,520	184	-125%	-99%	0.56
All	2009.0			17,941,047	12,516,613	3,481,726	-43%	-81%	0.38

Glossary

Baseflow. Streamflow that occurs in-between stormflow-generating rains. Baseflow is derived from groundwater discharge.

Best Management Practice (BMP). A specific action, process, method, or technology that is effective and practical for preventing or reducing pollution from nonpoint sources. Management practices are selected for appropriateness to the source, location, and climate.

Cumulative Impacts. Impacts that arise from the sum of all past, present, and reasonably foreseeable future actions. Cumulative impacts can arise from individually minor but collectively significant actions taking place over a period of years.

Design Storm. A hypothetical large rare rainstorm. Sometimes referred to as an "event". This concept is best understood as an example. Consider a location for which the 1-hour 10-year rainstorm is 2.4 inches. This storm delivers 2.4 inches of rain in one hour and has a 10-year recurrence interval. This means that in any given year there is a 1 in 10 chance that the largest 1-hour rainfall will exceed 2.4 inches.

Geographical Information System (GIS). A computer system for storing and analyzing geographically referenced (map-like) data.

Intermittent stream. A stream that carries water for months at a time but periodically ceases to flow when shallow groundwater is depleted. Intermittent streams differ from **ephemeral streams** in that ephemeral streams are not fed by groundwater and carry water only after rains.

Interrupted stream. A stream that carries water through much of its length but has sections of dry streambeds.

LEED refers to the Leadership in Energy and Environmental Design program, which provides developers with a framework for identifying and implementing practical and measurable green building design, construction, operations, and maintenance solutions (U.S. Green Building Council. 2005).

Losing Streams lose water to streambed infiltration. This means that it is possible for discharge to decrease in a downstream direction. Loads generated upstream may not reach the ocean. Note that a stream may be losing in some reaches and gaining in others.

Loads refer to the amount of pollutant leaving a development or watershed in a specified amount of time. Typical units are kilograms per year or kg per storm event. Loads are relevant to the ecosystem in its entirety while concentrations (amount of pollutant in a unit volume of water) are relevant in terms of stress to individual organisms.

Peak Flow. The maximum discharge experienced during a runoff event or during the course of year. A stream's discharge (synonym flow) is the amount of water flowing past a given point in a given amount of time. Units are volume of water per units time: typically cubic feet per second (cfs) or cubic meters per second (cms).

Perennial stream. A stream that carries water at all times. Perennial streams are fed both by stormwater runoff and by groundwater.

Raster. GIS data or models that represent a spatially continuous variable (e.g. land use or rainfall) as an equally-spaced grid of values.

Runoff. As used in this report, runoff is synonymous with stormwater and refers to water flowing over the ground or in streams in response to a hard rain. Runoff occurs during and immediately after a rainstorm. Occasionally this term is used to denote all water in streams, whether derived from "surface" runoff or from groundwater.

Secondary impacts. Impacts which are caused by an action and are later in time or farther removed in distance, but are still reasonably foreseeable. These indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems. (From Chapter 11-200, HAR)

Section 303(d) List. The federal Clean Water Act requires states to regularly describe overall status of water quality statewide and submit a list of waters that do not meet state water quality standards. The most-recent document and list developed by the Hawai'i Department of Health is entitled ***2006 State of Hawai'i Water Quality Monitoring and Assessment Report: Integrated Report to the U.S. Environmental Protection Agency and the U.S. Congress Pursuant to Sections 303(D) and 305(B), Clean Water Act (P.L. 97-117)***, better known as the Section 303(d) list.

Stormwater is water flowing over the ground or in channels immediately after a hard rain. Stormwater is contrasted with **baseflow**, which is derived from groundwater and comprises the small but steady streamflow in-between hard rains.

Stormwater Assessment. Prediction of the effect of an activity on stormwater. Effects could include changes to the amount runoff, changes to the timing and magnitude of peak flows, and initiation of streambank erosion. This term is most often used in the context of an Environmental Impact Statement.

Total Maximum Daily Load (TMDL). An estimate of the amount of given pollutant that can enter a given stream or receiving waters (in a given amount of time) without impairing water quality. The maximum allowable load is typically allocated between different uses, for example, contributions from sewage treatment plants, agriculture, and urban stormwater runoff. The TMDL is a non-binding management measure within the Clean Water Act, implemented by the Hawai'i Department of Health.

Total Nitrogen (TN). "Total" nitrogen refers to the sum of all forms of nitrogen, including particulate, dissolved, inorganic (e.g. nitrate), and organic (e.g. decomposed leaves) forms. Different forms of nitrogen have different levels of bioavailability, but nitrogen changes form readily so it is traditional to analyze all of them together.

Total Phosphorus (TP). "Total" phosphorus is the sum of all forms of phosphorus, including particulate, dissolved, inorganic (e.g. orthophosphate), and organic (e.g. decomposed leaves) forms. In streams a high percentage of phosphorus is in particulate form, so BMPs that reduce sediment loads are usually effective in reducing the amount of phosphorus that enters streams.

Total Suspended Solids (TSS). TSS concentration refers to the amount of sediment (either mineral or organic) in water and has units of mass of solids per unit volume of water.

Water Quality Standards. The criteria used by the State uses to evaluate whether its waters are healthy. Water quality standards address physical, chemical and biological aspects of water quality and set the bar for minimum acceptable quality.

Yield. Pollutant loads divided by the acreage of the area that generates the runoff. Yields have units of mass of pollutant per unit time per unit area. Yields are useful in comparing different geographic areas or examining spatial variations.