University of Iowa

(SOA) 2017 Student Case Study Challenge

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1 Executive Summary

In this Akua Island coastal management project, we were tasked to propose an optimal designation of zones to a given set of private/public uses. For this purpose we used the given current and past environmental data, and the constraints imposed by the coastal commission that any acceptable solution should meet. Apart from these, we took into account published reports on methoodologies used by coastal zones for similar exercises, which gave us insights into developing a priority among different uses. The key components of our methodology include an extreme value theory based modeling of the sea level data, multiple use of statistical decision trees, and an optimality criterion which took into account desirable characteristics for each use. One rather surprising observation from this exercise is that the constraints imposed by the commission on zones designated for conservation were quite restrictive to permit only a few feasible solutions when combined with other very natural requirements. While we strongly believe that our solution is optimal given the framework above, we also believe that the solution we propose cannot be uniformly improved upon to better serve all competing interests.

2 Purpose and Background

2.1 Background

Akua is an island in the tropics which has a small population and large undeveloped coastal zones. The coastal marshes and endangered species are valuable natural resources on the island.

As a team of actuarial consultants, our goal for this project is to help the Akua Coastal Commission implement their new 2017 Coastal Act. Based on the mission of the commission, our task is to maximize the usage of undeveloped coastal zones for promoting development of public land and middle class employment, while more importantly, to protect, conserve, restore and enhance the environment of the Akua Island coastline.

The challenging parts of this project include balancing the competing interests of industry stakeholders and environmentalists, and quantifying this problem using actuarial related methods.

2.2 Interpretation of Objectives and Rules

As part of the 2017 Coastal Act, the commission made a set of rules and objectives for the future development of Akua's coastline. Before implementing any methods and models, we carefully investigate the rules and objectives, where the result is shown in the figure 2.1 below.

Land use / Characteristic	Public		Private			
	Conservation	Recreation	Agriculture	Fisheries	Housing	Other
Areas	30%		10%	10%	10%	10%
Duck Population	√					
% Wetland	√					
Coastline length	√	√		√	√	
Grassland		√	√		√	
Forest		√				
Snapper				√		
Organic matter			√			
Low risk		√			√	

Figure 2.1: Rules and Objectives

Specially, all public land designations must contain at least two connecting zones, here connecting means two zones are touching at more than a narrow point.

2.3 Literature Review

In the stage of information gathering, we read some relevant papers on coastal zone planning, sea level rise and its coastal impacts, Geostatistics, Spatial Analysis, etc. A subset of these that we employed for this exercise are given in the bibliography.

For coastal zone planning, researchers have studied both its theoretical and modeling aspects . For instance, Davidson (1978b) suggests that adverse environmental effects always outweigh any economic benefits in coastal management decisions. Nagao and Morikawa (1985) proposed an activities allocation model for planning the efficient utilization of coastal zones while preserving the environment.

For sea level rise and its coastal impacts, Cazenave and Cozannet (2014) summarize the most up-to-date knowledge about sea level rise and its causes; present sea level projections methods and suggest the response of coastal systems to sea level rise is highly dependent on local natural and human settings. Virginia Coastal Zone Management Program (2016) shows that developing an inventory of wetlands and potential wetlands is an important tool to conserve wetlands, especially in the face of sea-level rising and climate change.

3 Data Modeling and Methodology

3.1 Identifying High Risk Zones based on Historical Sea Level

Probably the most widely used risk measure is Value-at-Risk(VaR). Given a loss random variable L, VaR of L at confidence level α is given by

$$VaR_\alpha(L) = \inf\{l \in \mathbb{R} : P(L > l) \leq 1 - \alpha\}.$$

VaR estimates how much of a portfolio one might lose at a given probability level. It plays a prominent role in many financial regulatory laws like Solvency II and Basel II Accord. For most of the zones, like zone 1 and zone 3, we are given almost complete historical sea level data for the past 25 years. A few zones have a sea level data for a very limited time period. After identifying zones with less than 100 months data (as zone 2, zone 11-13 and zone 16) we find that these zones have significant high average altitude at 100 meters inland. The lowest value is 3.8 meters for these zones. Also we noticed that most historical sea level is lower than the current sea level, which means we are currently at a historical high sea level. Also, the variation in the past 25 years has been less than 1m, which implies that it is highly unlikely that it will surpass the threshold of 3.8 meters in next 5 years.

Generalized extreme value distribution(GEV) (McNeil et al. (2015)) combines Gumbel, Frechet and Weibull families and plays a key role in Extreme Value Theory, it has distribution function as

$$H_\xi = \begin{cases} \exp(-(1+\xi x)^{-1/\xi}) & \xi \neq 0 \\ \exp(-e^{-x}), & \xi = 0 \end{cases}$$

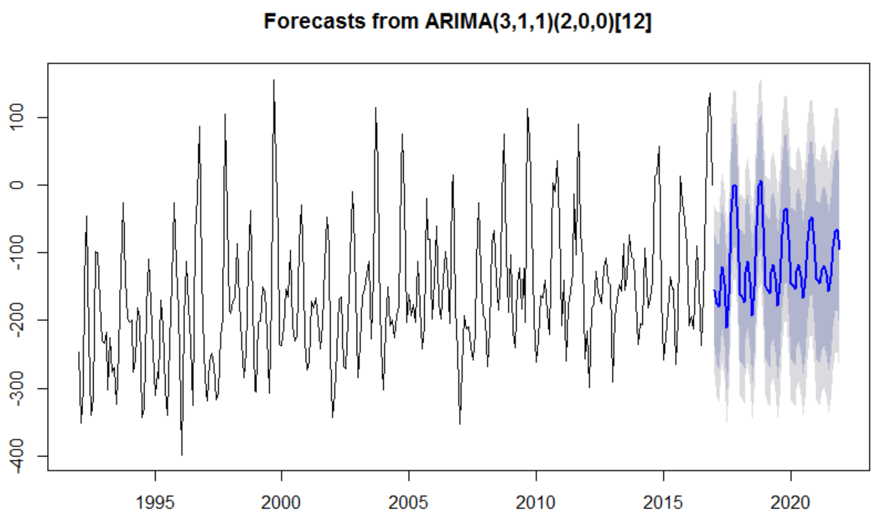

Figure 3.1: Time series predicting for zone 1

Due to limitation of existing data, it is hard to find a reasonable model to simulate missing values which will be reasonable for extreme value modeling purposes. But for the purpose of assigning usage for each zone, the goal more directly relevant is to identify risky zones. The methodology we adopt is to fit GEV to the historical data, then calculate VaR based on the fitted distribution. The metric for risk from sea level increase that we employ is defined as the ratio of VaR to the average altitude 100 meters inland. As shown in Figure 3.2 the GEV fits the data quite well, also time series prediction(Figure 3.1) and return plot(Figure 3.3) show that future sea level in next 5 years will stay close to current levels relative to average height at 100m inland.

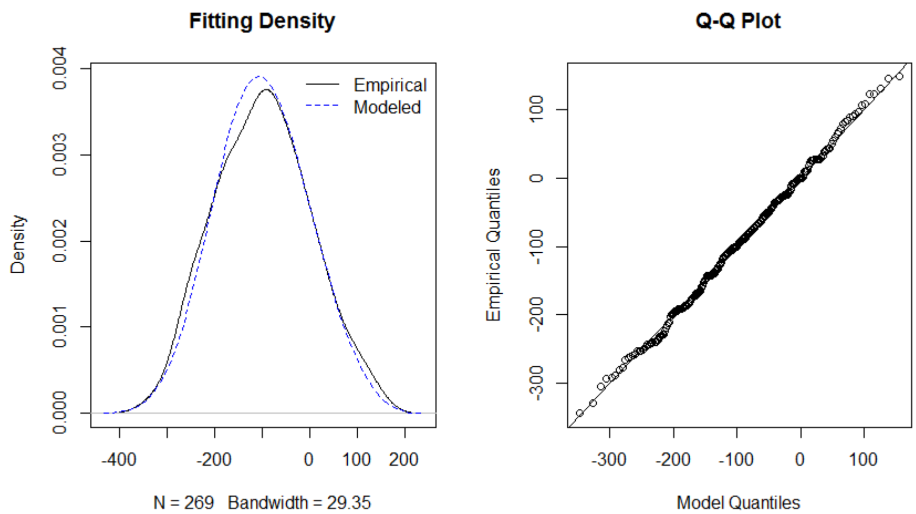

Figure 3.2: GEV fitting for zone 18

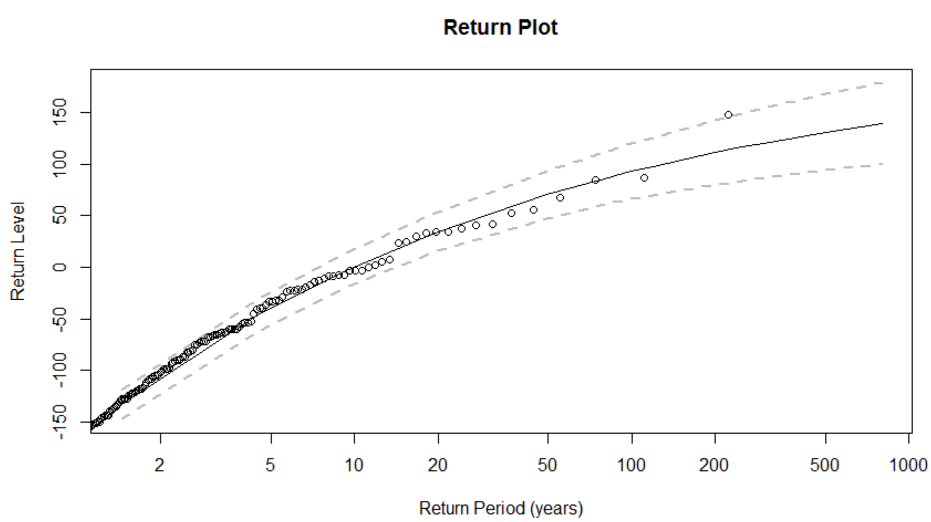

Figure 3.3: Return plot for zone 18

3.2 Finding Feasible Solutions

Each land use needs to meet certain requirements to be allocated appropriately. In this section we utilize this given information and our sea level risk metric with classification metods to arrive at feasible solutions. First, for each characteristic, we use a level of quantile in a manner which allows for a sufficient number of zones. This choice was made by trial and error; it is worth mentioning that given time this can be easily automated as well. We use decision tree to identify the zones that possess the characteristics need for each use excluding the use "other economic development". After implementing decision tree, we arrive at a good starting point from which we can arrive at an optimal designation for the 20 zones. Based on these feasible allocations for each zone found by the statistical approach, we proceed to decide the best possible allocation in our final stage. Although the result of decision tree doesn't guarantee us an optimal solution to the problem, it places us on a path towards finding one.

Zone	**Public**		**Private**		
	Agriculture	Fishing	Private_housing	Conservation	Recreation
1					
2			Private_housing		Recreation
3					
4					
5					
6	Agriculture		Private_housing		
7		Fishing			
8		Fishing			
9					
10		Fishing			
11		Fishing		Conservation	
12		Fishing	Private_housing		
13					
14		Fishing		Conservation	
15		Fishing		Conservation	
16		Fishing		Conservation	
17	Agriculture	Fishing	Private_housing	Conservation	Recreation
18	Agriculture	Fishing		Conservation	
19		Fishing	Private_housing		

Figure 3.4: Decision tree

4 Results, Conclusions and Discussion

California is the state which has been implementing an innovative strategy for coastal management since 1972 (Davidson (1978a)), so the innovative strategies used in California can relax the competing interests of industry stakeholders and environmentalists. Therefore, the strategies for coastal zone management and planning in California are implemented again to allocate an appropriate use to each undeveloped zone in Aqua Island together with the decision tree result (Table **??**) and the identified high risk of sea level zones earlier (Zones 7, 14, 15, 16, and 18).

The result of the allocation is displayed in Table 4.1, and then, the amount of each factor allocated to each 6 different uses is calculated for comparison (Table 4.2).

According to Davidson (1978a), public developments should be prior to private developments and it is highly recommended to have recreational zones next to already developed areas, moreover, Conservation took priority over Recreation among public developments because the endangered Akua ducks are the first factor to consider among others. Following these strategies, zones with a large Akua duck population, a large wetland area together with a low snapper exploitation rate are designated to conservation first. Low snapper exploitation rate is considered for conservation zones because low rate will provide enough food for the ducks. As a result, zones 15, 16, 17, and 18 are designated for conservation, and it matches with the decision tree result. Besides, conservation zones have the largest wetland area and the duck population, with the lowest snapper exploitation rate compared to other uses (Figure 4.2). Next, recreation is allocated to zones 1 and 2, which have large forest and grassland area among those zones that are next to already-developed areas with a low risk of sea level increase.

The coastal-dependent development takes priority over other kinds of development (Davidson (1978a)). Therefore, fishing became the first thing to consider among the private developments. As a result, fishing took the zones with the longest coastline and the lowest snapper exploitation rate among the remaining zones. However, it also resulted in having large areas of wetland, grassland, and forest which are not necessary for the fishing, which can affect the allocations for agriculture and private housing later.

Between agriculture and private housing, agriculture is the one which highly depends on natural

Coastal Zone	Recommended Use of Zone
1	Recreation
2	Recreation
3	Other
4	Agriculture
5	Agriculture
6	Agriculture
7	Other
8	Private Housing
9	Other
10	Fishing
11	Fishing
12	Private Housing
13	Other
14	Fishing
15	Conservation
16	Conservation
17	Conservation
18	Conservation
19	Private Housing
20	Agriculture

Figure 4.1: Allocation of zones

Allocation	Wetland Area (km^2)	Grassland Area (km^2)	Forest Area (km^2)	Aqua Duck Population (number of ducks)	Snapper Exploitation Rate	Soil Organic Matter	Coast Line (km)	Wetland %
A	13.08	88.65	38.25	38	28%	8%	43.00	9%
C	17.18	109.60	20.96	672	6%	7%	76.50	11%
F	8.36	49.79	31.37	81	7%	7%	26.10	8%
P	7.97	74.09	12.29	106	8%	5%	35.90	8%
R	6.30	32.62	21.49	0	64%	3%	33.60	10%
Other	6.33	80.10	13.34	40	27%	3%	29.30	6%

Figure 4.2: Amount of each factor allocated to each use
(A=Agriculture, C=Conservation, F=Fishing, P=Private Housing, R=Recreation)

resources, so agriculture took priority over private housing. Therefore, the zones with large grassland areas and large amounts of soil organic matter in grassland are designated agriculture first. And then the zones with large grassland area and long coastline are designated for private housing use among the remaining undeveloped zones with a low risk of sea level increase. Because private housing is the last land use to consider and many suitable zones with a huge grassland and a long coastline are already taken by prior land uses, total grassland area and total coastline length allocated to private housing are not huge compared to other land uses (Figure 4.2).

Zone 7 has a distinguishable characteristic that can be suitable for fishing and private housing, but its high risk of sea level increase and high snapper exploitation rate make it fall in others group to make it recover from the problem of overfished. Therefore, the zone 7 is now reserved for other forms of economic development together with the zones 3, 9, and 13 which do not have distinguishable characteristics compared to other coastal zones in Akuna Island. Some zones have multiple plausible assignments of usage, like zone 19 and zone 20. As Aqua duck relies on snapper for good, it is better that these zones are not assigned for fishery. While conservation takes priority over private developments, this is one of the rationale why zone 19 is assigned for private housing and zone 20 for agriculture. If we take this reasoning into consideration, all the results of zones 14 — 20 will match the results from the decision tree.

Use	% of Total Area
A	21.73%
C	23.46%
F	14.73%
P	14.97%
R	9.38%
Others	15.73%

Figure 4.3: Proportion of total area allocated to each use
(A=Agriculture, C=Conservation, F=Fishing, P=Private Housing, R=Recreation)

Finally, the figure 4.3 above was constructed to check if the allocation has met the requirement of minimum area needed. According to the table, the requirements are successfully met that at least

10% of the 20 coastal zones are designated for each of 6 private developments: Agriculture, Fishing, Private Housing, and Other economic development, and 32.84% of total area are allocated to the public developments: Conservation and Recreation.

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5 Appendix

5.1 Identifying high risky zones

```
##### Extremes
library(forecast)
library(tseries)
library(extRemes)
library(ggplot2)
library(pbkrtest)

SL<-read.csv("sea level data.csv",header=F)



# for zone i
f=function(i){
a=SL[,i]
t=a[!a=='XXXXX']
t[t==-99999]=NA
s=as.numeric(as.character(t))
return(s)}

seale <- f(18)
fitGEV <- fevd(seale, type = 'GEV', na.action = na.omit)
par(mfrow = c(1, 2))
plot(fitGEV, 'density', main = 'Fitting Density')
plot(fitGEV, 'qq', main = 'Q-Q Plot')

p <- fitGEV$results$par
qevd(0.99, loc = p[ 1 ], scale = p[ 2 ], shape = p[ 3 ])
par(mfrow = c(1, 1))
plot(fitGEV, type = "rl", main = 'Return Plot')
```

```
#Average altitude measurement 100m inland from December 2016 Mean Sea Level (m)
alti=c(9.5,6.4,3.6,0.4,0.3,3.9,0.4,2.6,2.8,4.8,4.6,3.9,3.8,0.6,0.3,0.1,3.5,0.4,3.8,7.2)
h=1:20
for(i in 1:20){
    datumMAX <- f(i)
    fitGEV <- fevd(datumMAX, type = 'GEV', na.action = na.omit)
    p <- fitGEV$results$par
    h[i]=qevd(0.99, loc = p[ 1 ], scale = p[ 2 ], shape = p[ 3 ])
}
#ratio
h/1000/alti
#identify risky zones
(h / 1000 / alti > 0.1)*(1:20)
[1] 0 0 0 0 0 0 7 0 0 0 0 0 0 14 15 16 0 18 0 0
```

5.2 Decision Tree

```
rm(list = ls())


library(xtable)


#setwd(="/Users/JL/Desktop/SOA case study")
raw=as.matrix(read.table('current_data.txt'))


sortchar=function(q){
    wet = raw[, 1] * raw[, 2]
    grass =raw[, 1] * raw[, 3]
    forest = raw[, 1] * raw[, 4]
    new=cbind(wet, grass, forest, raw[, 6], 1 - raw[, 7], raw[, 8], raw[, 9],raw[,3])
    qs=q
    for(i in 1:length(q)){
        qs[i]=quantile(new[,i],q[i])
    }
    new >= matrix(rep(qs, 20), byrow = TRUE, 20)
}


#sea level risk
risk <- rep(0, 20)
risk[c(7, 14:15, 18)] <- 1


# q are the cutoffs percentages, its elements represent wetland, grassland, forest,
#duck, snapper, organic and coastline respectively
sortdata <- sortchar(c(0.5,0.5,0.5,0.5,0.3,0.7,0.2, 0.5))
colnames(sortdata) <- c("wet", "grass", "forest", "duck", "snapper",
                        "organic", "coastline",'grass_per')
sortdata
```

```
# wet grass forest  duck snapper organic coastline
# 1    2      3      4      5       6        7

Agriculture <- function(data = sortdata, i){
    if(data[i, 6] == "TRUE" && (data[i, 2] == "TRUE"||data[i,8]== "TRUE")){
        ag <- c("Agriculture")
    }else{
        ag <- c(" ")
    }
    ag
}

Fishery <- function(data = sortdata, i){
    if(data[i, 7] == "TRUE" && data[i, 5] == "TRUE"){
        fi <- c("Fishery")
    }else{
        fi <- c(" ")
    }
    fi
}

Private_housing <- function(data = sortdata, i){
    if(data[i, 7] == "TRUE" && data[i, 2] == "TRUE" && risk[i] == 0 ){
        ph <- c("Private_housing")
        }else{
        ph <- c(" ")
        }
    ph
}
```

```
Conservation <- function(data = sortdata, i){
    if( (data[i, 1] == "TRUE" || risk[i] == 1)&&data[i, 4] == "TRUE" ){
        co <-c("Conservation")
    }else{
        co <- c(" ")
    }
    co
}

Recreation <- function(data = sortdata, i = 1){
    if(data[i, 3] == "TRUE" && data[i, 7] == "TRUE" && data[i, 2] == "TRUE" && risk[i] == 0){
        re <- c("Recreation")
    }else{
    re <- c(" ")
  }
  re
}

Fit_Agriculture=c(1:20)
Fit_Fishery=c(1:20)
Fit_Private_housing=c(1:20)
Fit_Conservation=c(1:20)
Fit_Recreation=c(1:20)


for (zone in 1:20){

  Fit_Agriculture[zone]=Agriculture(sortdata, zone)
  Fit_Fishery[zone]=Fishery(sortdata, zone)
  Fit_Private_housing[zone]=Private_housing(sortdata, zone)
  Fit_Conservation[zone]=Conservation(sortdata, zone)
```

```
  Fit_Recreation[zone]=Recreation(sortdata, zone)
}


Zone=c(1:20)
table=data.frame(Zone,Fit_Agriculture,Fit_Fishery,Fit_Private_housing,
                 Fit_Conservation,Fit_Recreation,row.names = NULL)
#rownames(table)=c("Zone")
colnames(table)=c("Zone","Agriculture", "Fishery", "Private_housing",
                  "Conservation", "Recreation")


TABLE=xtable(table,caption = "Decision Tree")
align(TABLE)="|r|l|l|l|l|l|l|"
print(TABLE, floating = TRUE, latex.environments = "center",scalebox = 1,
      include.rownames = FALSE)
```

5.3 MAP OF LAND DESIGNATION

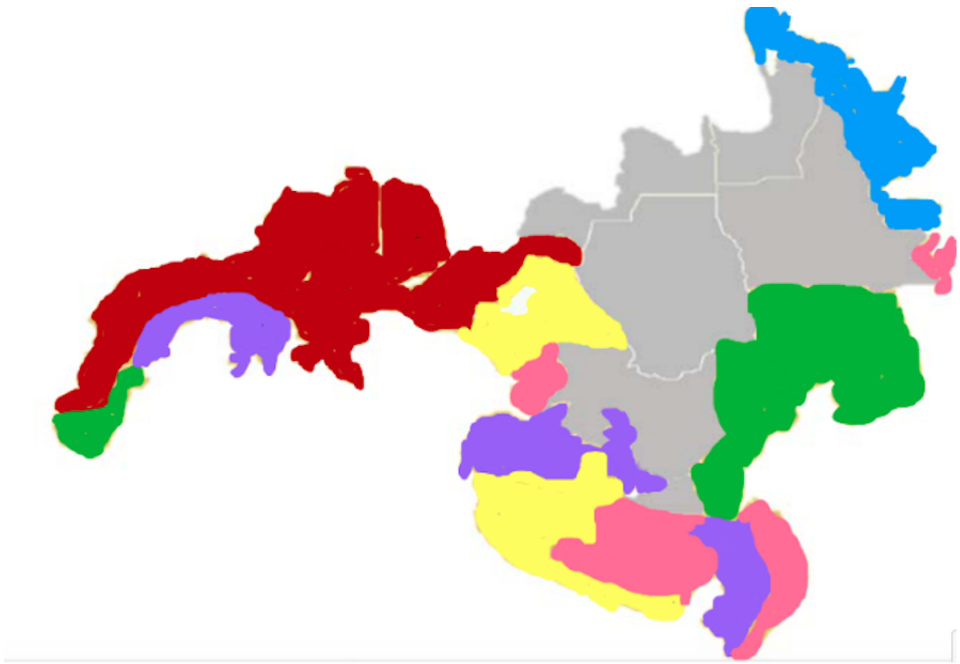

Figure 5.1: Map of land use
(Green:Agriculture, Red:Conservation, Yellow:Fishing, Purple:Private Housing, Blue:Recreation)