Technical report: a catchment slope assessment using DEM slope (land) and REC slope (river)

Objectives:

(1) Extract land slope information adjacent to river segments (buffer zone) using DEM

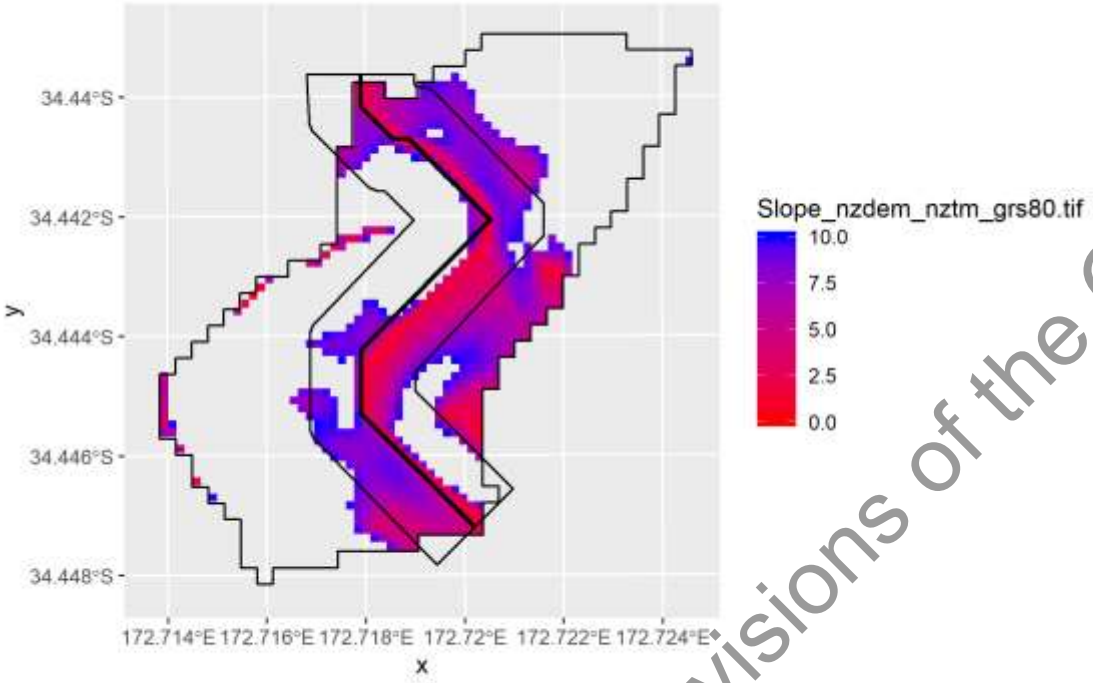
(2) Assess buffer zone slopes based on REC slopes

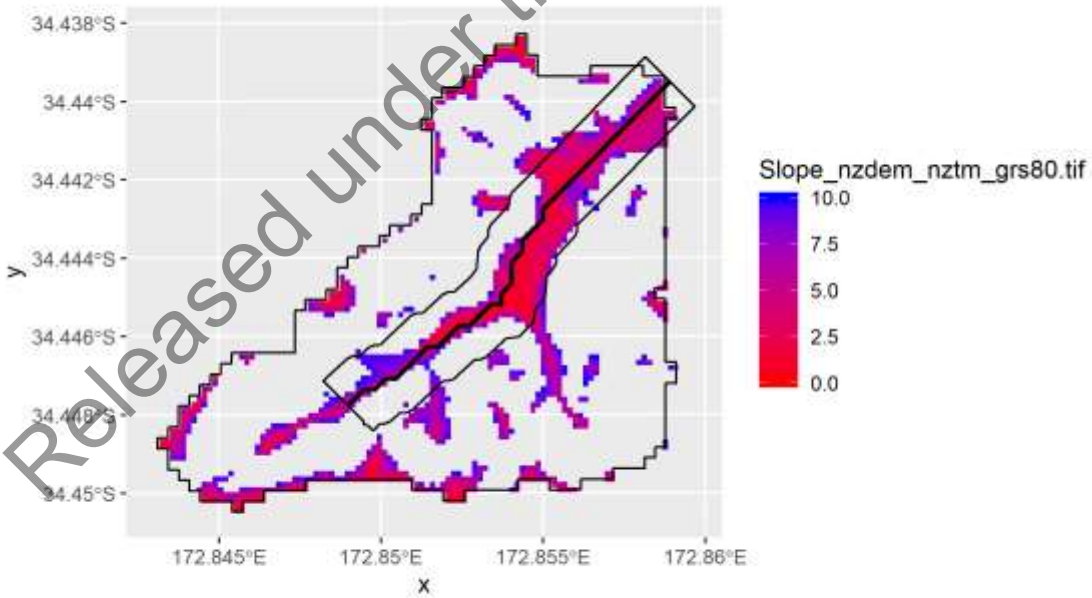
O/1: extract land slopes adjacent to river lines

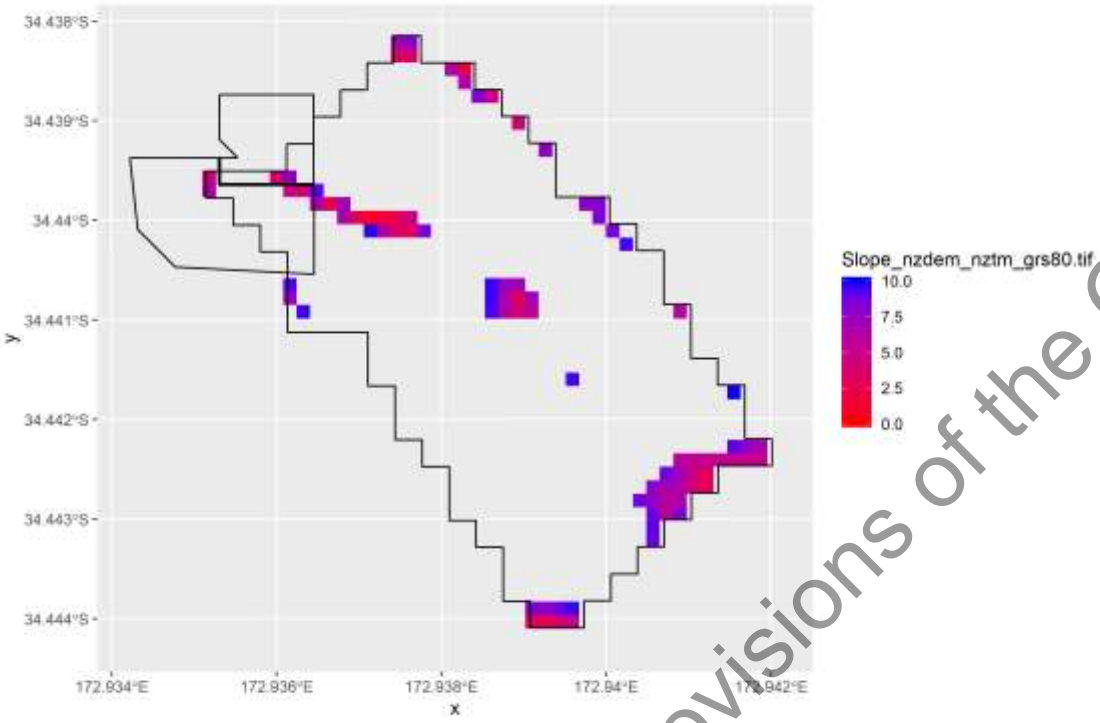
- Approximately 20% of REC segments were randomly selected (N = 124,964)
- Digital Elevation Model (DEM, 15m grids) data were used to calculate land slopes across NZ
  - methods: slope raster function (ArcGiS Pro)
- Buffer zone was defined as the 100m either side of the REC2 river lines
  - methods: st_buffer function (sf package, R)
  - methods: buffer shapes were divided into each side by GIS operation (R)
- For each REC segment, we extracted information on:
  - REC river slope
  - Buffer zone mean slopes (each side separately)
  - Other relevant properties of buffer zone and the REC contributing catchment (e.g. area)

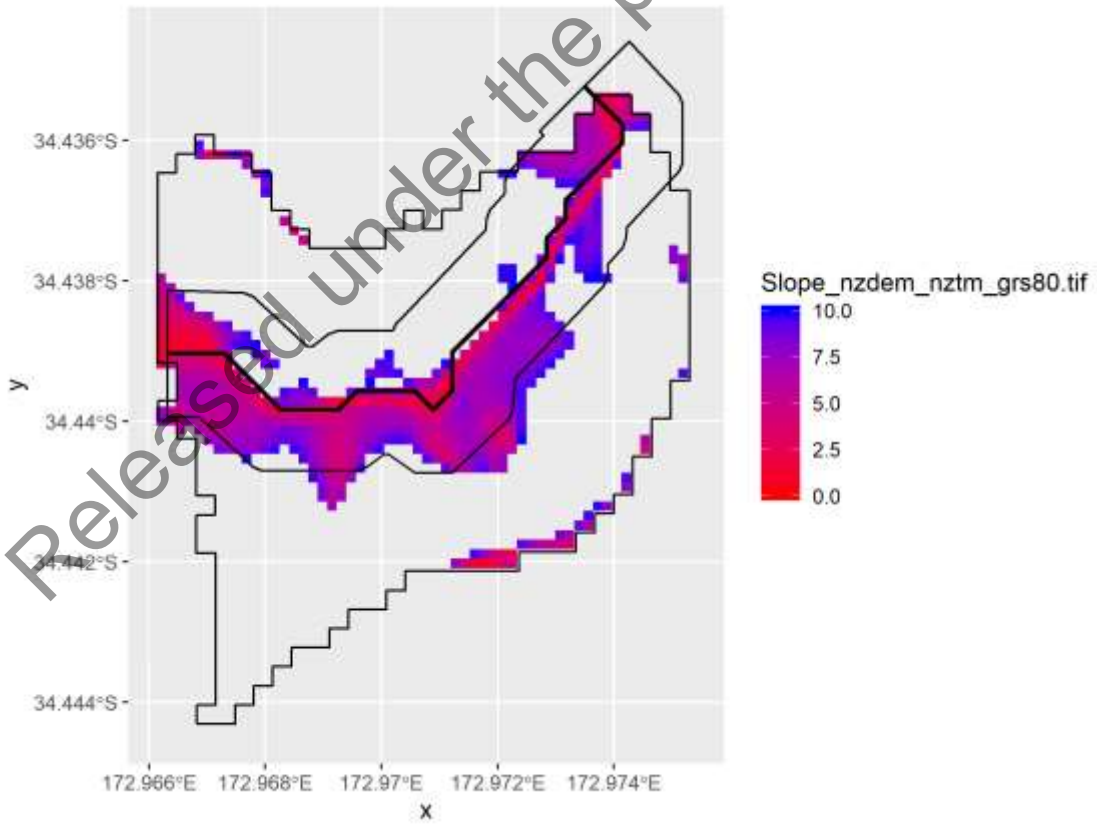
Example REC images with buffer areas (next page)

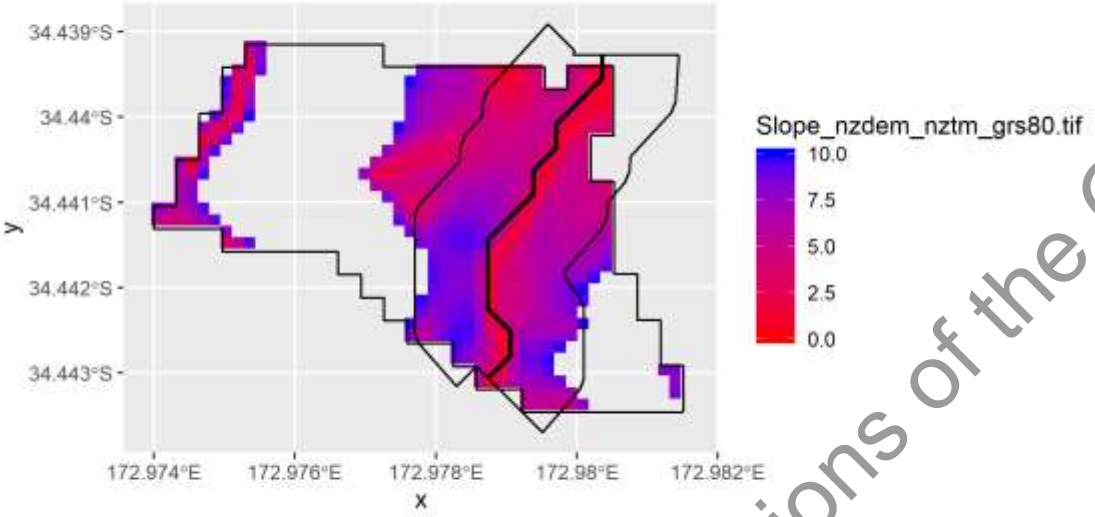
Note, no colour indicates pixels with slopes greater than 10 degrees.

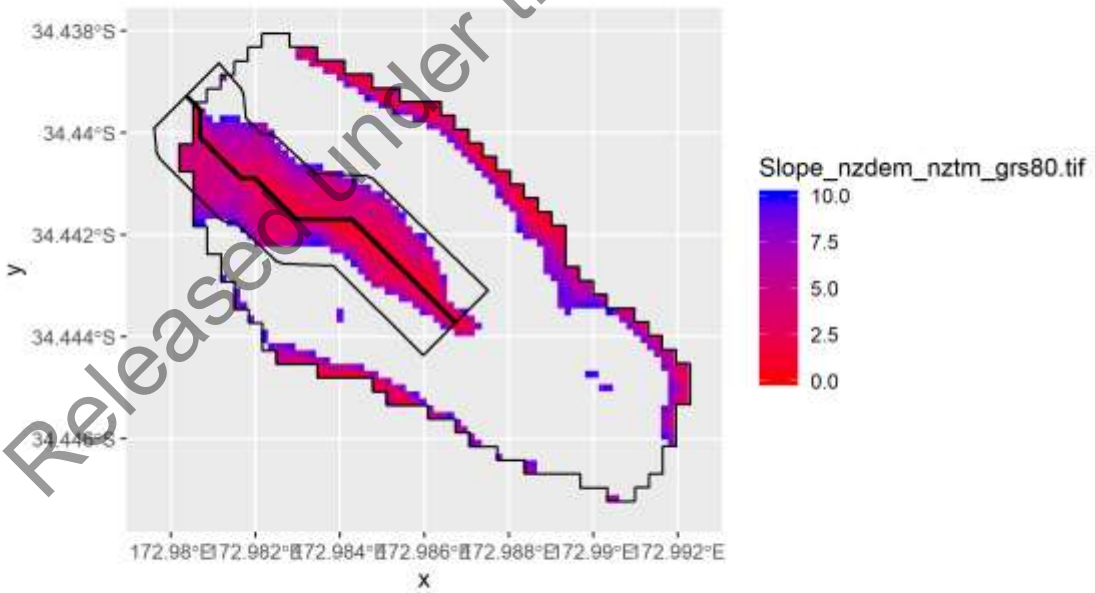


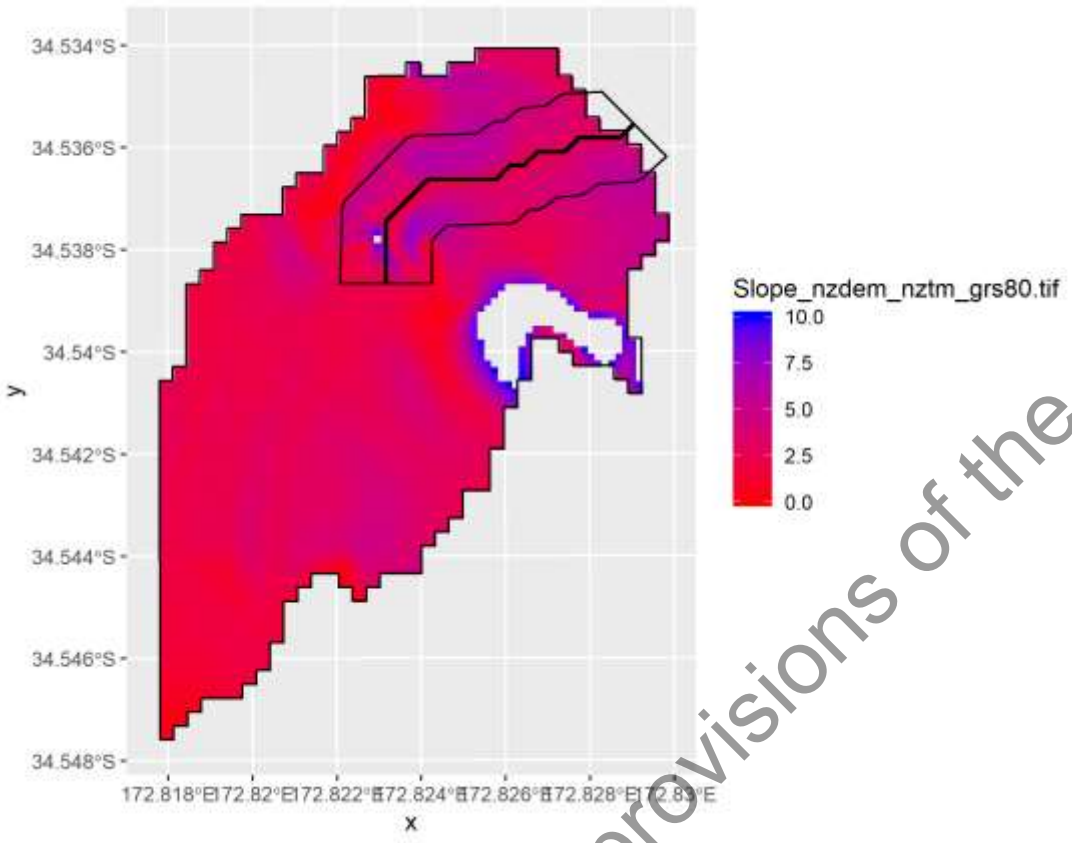


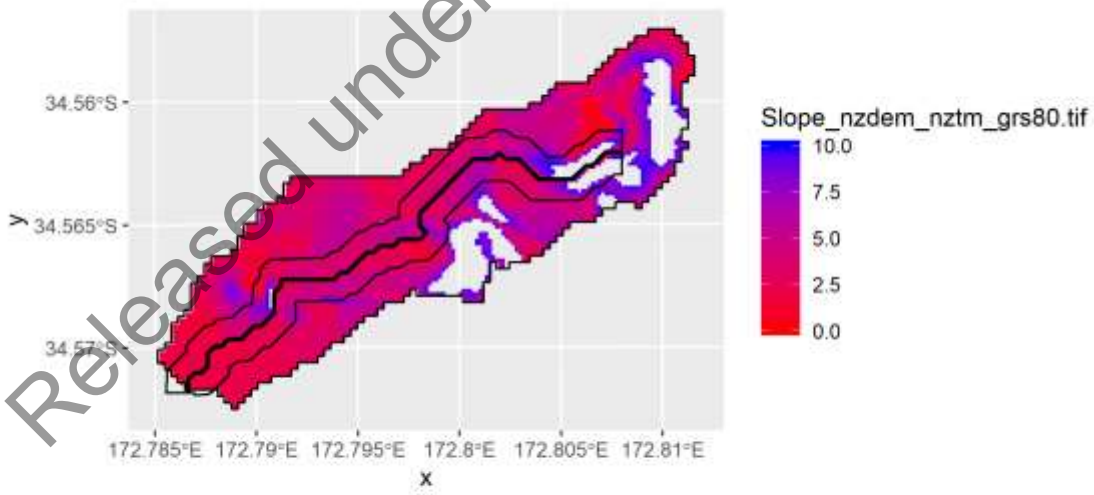












What do the data look like?

```
##              region nzsegments cat_id   rec_area rec_meanSlope rec_ncell
## 1 West Coast Region   12114290 383161  282629.01     49.896295      1256
## 2      Otago Region   14177106 445972  293000.74     31.476578      1300
## 3     Tasman Region   10019871 288746   23381.94      4.945625       104
## 4 West Coast Region   12133728 402597 1124987.09     53.877657      5046
## 5   Taranaki Region    6149509 149506  771321.60     21.646339      3428
## 6 Canterbury Region   13095874 364745  501892.43     39.582508      2232
##   rec_ncellFlat seg_HydroID seg_StreamOrde seg_LENGTHDOWN seg_CUM_AREA
## 1             2      976617              1       38217.99     282629.0
## 2           252     1039397              4      314741.88  117424312.0
## 3           104      882177              5       61806.68  348831488.0
## 4             5      996216              1       25603.09    1124987.1
## 5           967      743277              1       12087.67     771321.6
## 6            10      958238              1      106661.24     501892.4
##   seg_Shape_Length seg_segslpmean  buf1_area buf2_area buf1_meanSlope
## 1         250.9312    20.56244912  11588.631 16584.350       43.850888
## 2         470.1072     2.11313778  43726.310 38477.428       12.968707
## 3         114.8085     0.07807766   2452.714  7113.959        3.923058
## 4        1048.0210    30.34850771  88713.517 98437.264       49.188900
## 5        1136.5582     6.22821431 115580.619 90747.039       39.669405
## 6         432.9181    14.46284503  38457.977 22529.118       39.603100
##   buf2_meanSlope IsErronous
## 1      36.253865      FALSE
## 2       5.917920      FALSE
## 3       3.024836      FALSE
## 4      53.996967      FALSE
## 5      30.147767      FALSE
## 6      30.945859      FALSE
```

O/2: Analyse relationships between REC and buffer slopes

```
# Scatter plots between REC slopes and buffer slopes


ggplot(data = data_bothBufs,
       aes(x = rec_meanSlope,
           y = buf_slpmean)) +
  geom_point(
    size = 0.1,
    alpha = 0.05
  ) +
  geom_smooth(
    color = "yellow"
  ) +
  geom_smooth(
    method = lm,
    color = "green"
  ) +
  geom_hline(
    yintercept = 10,
    linetype="dashed",
    color = "red",
    size = 1
  ) +
  coord_fixed()
```

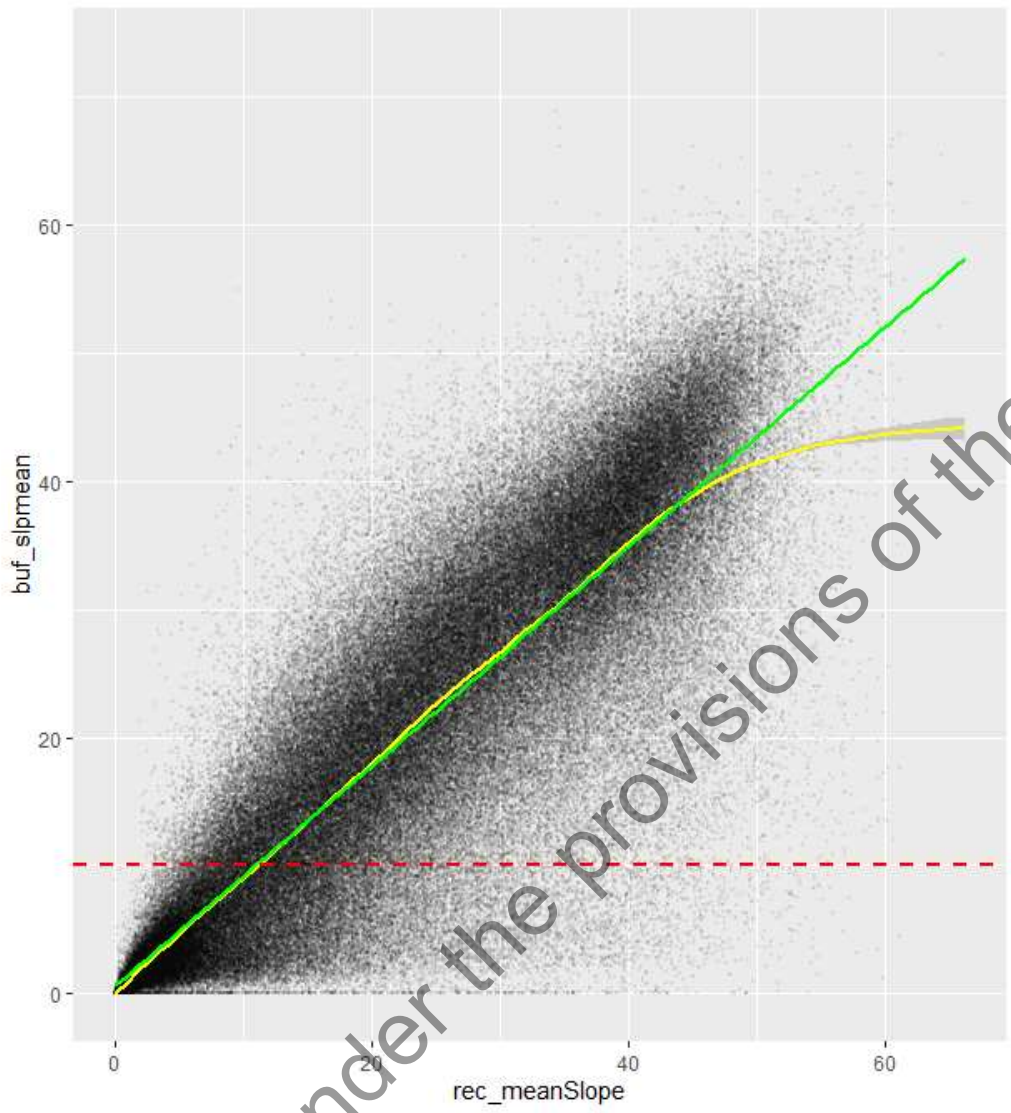


Figure. Relationship between REC slopes and land buffer average slopes. Green line is the least squared linear model, yellow line is the loess approximation, and red dash line is the 10 degrees threshold for land buffer zone slopes.

```
# for each stream orders

ggplot(data = data_bothBufs,
       aes(x = rec_meanSlope,
           y = buf_slpmean)) +
  geom_point(
    size = 0.1,
    alpha = 0.05
  ) +
  geom_smooth(
    color = "yellow"
  ) +
```

```
geom_smooth(
  method = lm,
  color = "green"
) +
geom_hline(
  yintercept = 10,
  linetype="dashed",
  color = "red",
  size = 0.5
) +
coord_fixed()  +
facet_wrap(. ~ seg_StreamOrde,
           nrow = 3)
```

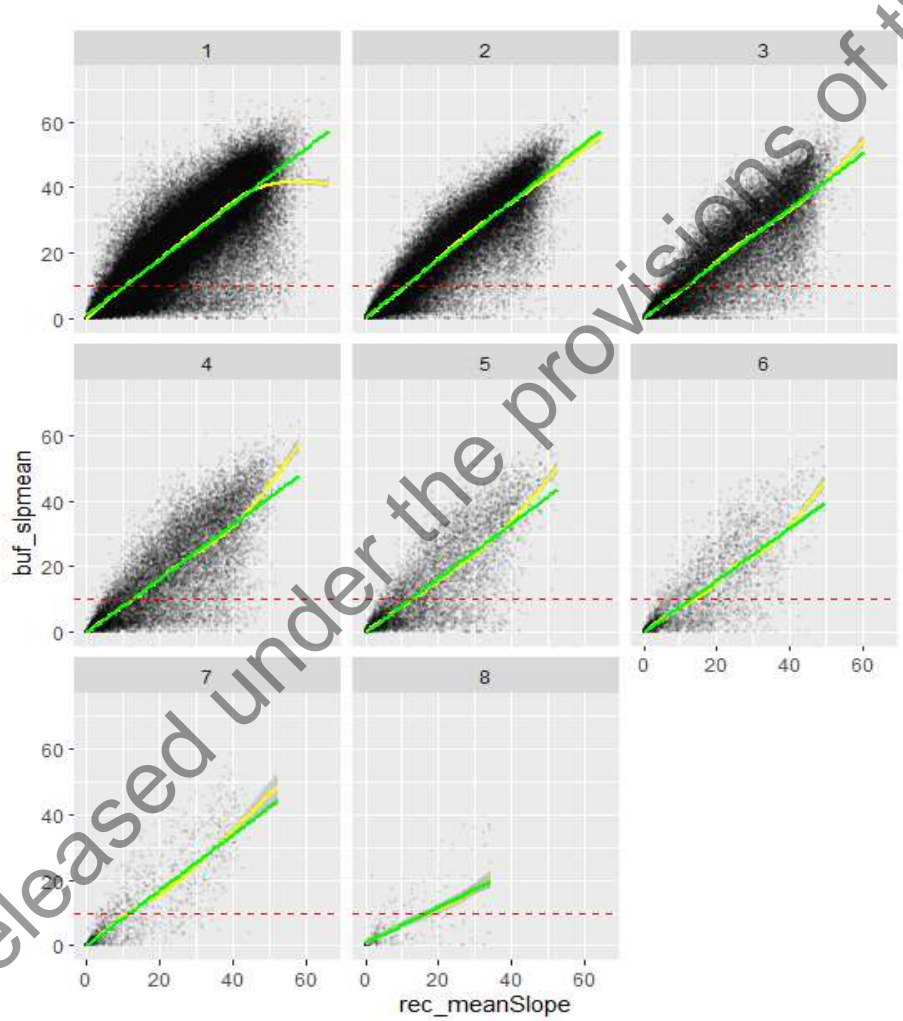


Figure. Relationship between REC slope and river buffer average slope. Green line is the least squared linear model, yellow line is the loess approximation, and red dash line is the 10 degrees threshold for buffer zone slopes. Each river order analysed independently.

Question:

What river slope threshold could be used to define the exclusion requirement?

How many segments or how much land area are we likely to "miss" or "over-capture" compared to the policy intent of consultation?}

Intention

- Either side of the land adjacent to rivers can be "under 10 degrees" to qualify for the low slope exclusion requirement.
- However, average land slopes are difficult to measure in real life whereas river slopes are easy to measure (both in real life, and in REC)
- Can we incorporate our intention (stock exclusion on land under 10 degrees) using river slope as a proxy?

Approach:

- condition: BOTH sides of the buffer zones are STEEPER than 10 degrees
- condition-met – segment does not require stock exclusion
- condition-unmet – segment requires stock exclusion

```
## this is the condition.

data_filtered$condition_met <-
  data_filtered$buf1_meanSlope > 10 &
  data_filtered$buf2_meanSlope > 10


## select the stream orders to analyse

myOrders <- 1:8 # range of 1-8

##
## conditions met (don't need to fence)
##

data_filtered %>%
 filter(condition_met) %>%
  filter(seg_StreamOrde %in% myOrders)  %>%
  select(rec_meanSlope,seg_StreamOrde) -> data_met
data_met$buf_condition = "met"

quantile_met <- quantile(data_met[,1],c(1:1000)/1000)

quantile_met <- as.data.frame(cbind(seq(1,1000,1)/10,quantile_met))
colnames(quantile_met) <- c("quantile","rec_meanSlope")
```

```
quantile_met$buf_condition <- "met"

print(paste0("Number of REC catchments met the condition: ", as.character(nro
w(data_met))))

## [1] "Number of REC catchments met the condition: 78852"

##
## conditions unmet (needs to fence)
##

data_filtered %>%
  filter(!condition_met) %>%
  filter(seg_StreamOrde %in% myOrders)  %>%
  select(rec_meanSlope,seg_StreamOrde) -> data_unmet
data_unmet$buf_condition = "unmet"

quantile_unmet <- quantile(data_unmet[,1],c(1:1000)/1000)


quantile_unmet <-  as.data.frame(cbind(seq(1,1000,1)/10,quantile_unmet))
colnames(quantile_unmet) <- c("quantile","rec_meanSlope")
quantile_unmet$buf_condition <- "unmet"

print(paste0("Number of REC catchments didn't meet the condition: ", as.chara
cter(nrow(data_unmet))))

## [1] "Number of REC catchments didn't meet the condition: 46112"

##
## hist plot
##
data_conditioned <- rbind(data_met, data_unmet)

ggplot() +
  geom_histogram(
    data = data_conditioned,
    mapping = aes(x = rec_meanSlope,
                  y = ..count..,
                  color = buf_condition),
    binwidth = 1,
    fill = NA,
    alpha = 0.5,
    position = "identity",

  ) +
  labs(
    x = "REC mean slope (degree)",
    y = "Number of REC"
  )
```

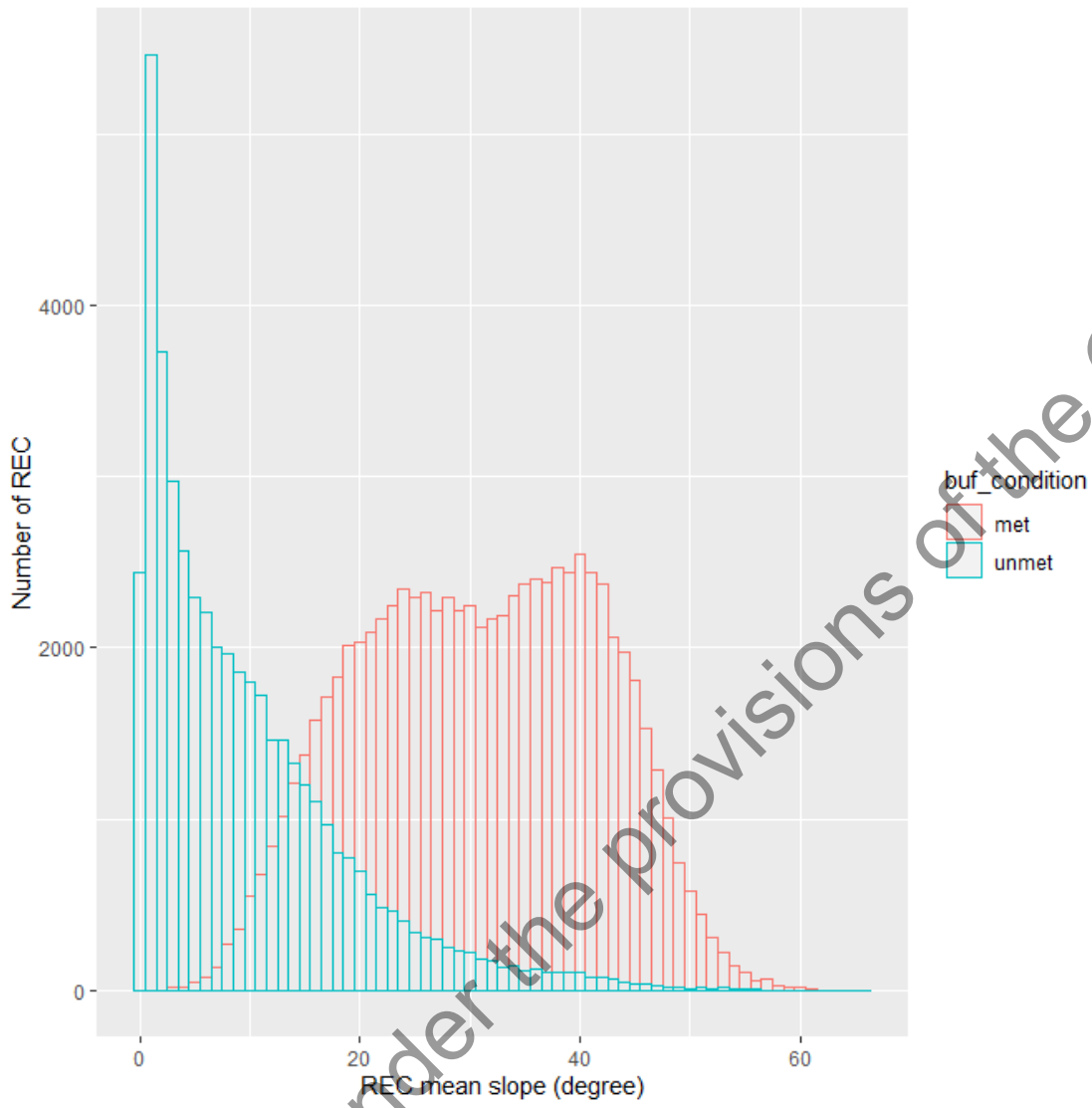


Figure. Distribution of the REC segments that "met" (do not have exclusion requirement) and "unmet" (do have exclusion requirement) the steep land definition.

```
##
## percentile plot
##

bufCondition_REC_quantile <- rbind(quantile_met, quantile_unmet)

ggplot() +
  geom_line(data = bufCondition_REC_quantile,
            mapping = aes(y = quantile,
                          x = rec_meanSlope,
                          color = buf_condition),
            size = 1
```

```
  ) +
  labs(
    x = "REC mean slope (degree)",
    y = "Quantile (%)"
  )
```

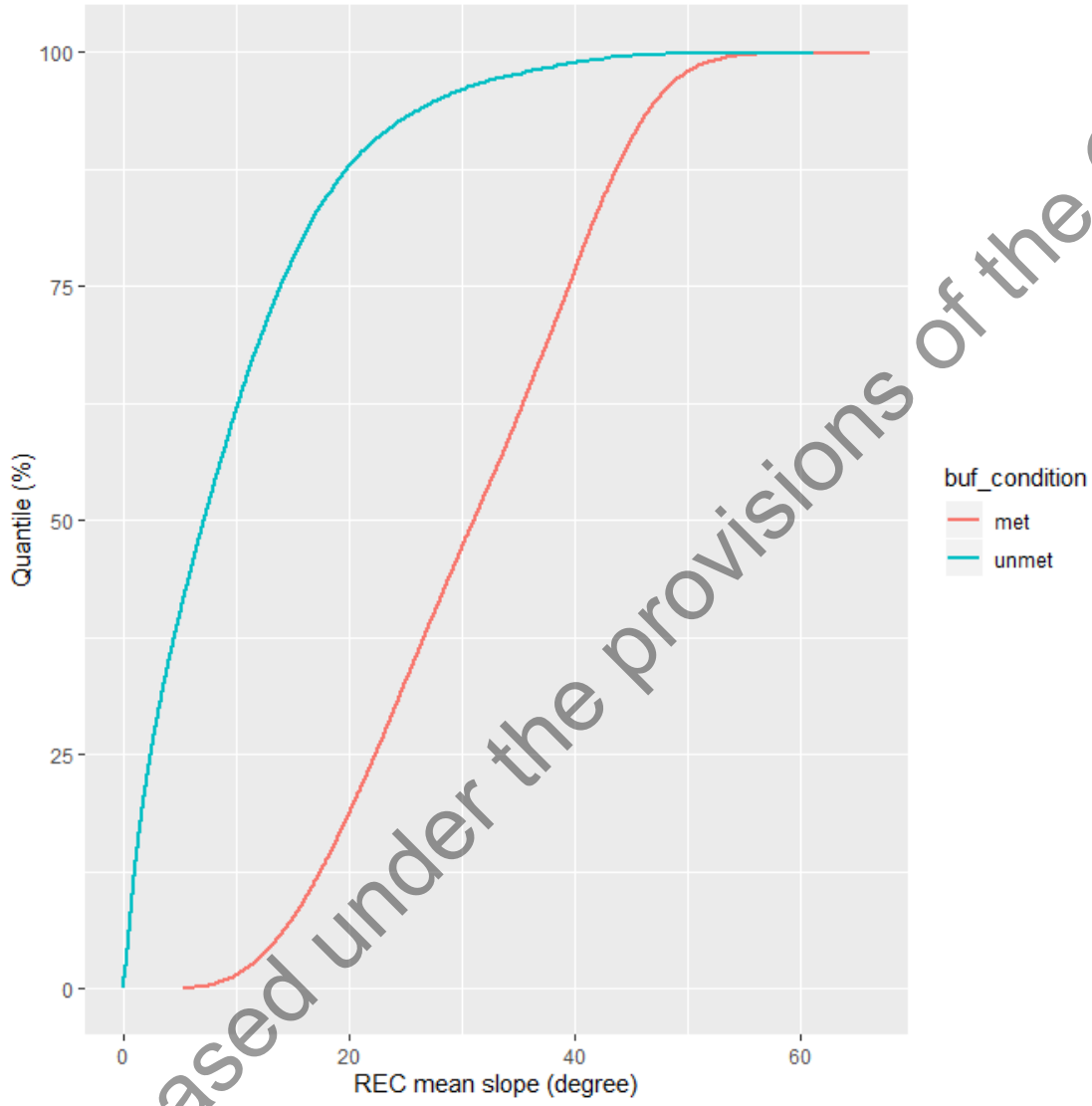


Figure. Cumulative proportion of the REC segments that "met" (no exclusion) and unmet (exclusion) the steep land definition.

```
CFM = data.frame(
  TP = double(),
  TN = double(),
  FN = double(),
  FP = double()
)

for (i in 1:60){
```

```
  thisCFM <- data.frame(
    TP = sum(data_met[,1] >= i),
    TN = sum(data_unmet[,1] <= i),
    FN = sum(data_met[,1] < i),
    FP = sum(data_unmet[,1] > i)
  )

  CFM <- rbind(CFM, thisCFM)
}

CFMp <- data.frame(
  REC_slope = 1:60,
  TPR = formattable::percent(CFM$TP, digits = 0)/sum(CFM[1,c(1,3)]),
  TNR = formattable::percent(CFM$TN, digits = 0)/sum(CFM[1,c(2,4)]),
  FNR = formattable::percent(CFM$FN, digits = 0)/sum(CFM[1,c(1,3)]),
  FPR = formattable::percent(CFM$FP, digits = 0)/sum(CFM[1,c(2,4)])
)

print(CFMp[5:20,],
      row.names = FALSE)

##  REC_slope  TPR TNR FNR FPR
##          5 100% 40%  0% 60%
##          6 100% 45%  0% 55%
##          7 100% 49%  0% 51%
##          8  99% 54%  1% 46%
##          9  99% 58%  1% 42%
##         10  98% 62%  2% 38%
##         11  98% 65%  2% 35%
##         12  97% 69%  3% 31%
##         13  96% 72%  4% 28%
##         14  94% 75%  6% 25%
##         15  92% 78%  8% 22%
##         16  91% 80%  9% 20%
##         17  89% 83% 11% 17%
##         18  86% 84% 14% 16%
##         19  84% 86% 16% 14%
##         20  81% 88% 19% 12%
```

	Pred.Steep	Pred.Flat
Actual.Steep	TPR	FNR
Actial.Flat	FPR	TNR

Above table. Confusion matrix related to different REC slope thresholds.

- TPR: % steep lands correctly predicted as steep lands (TP/(TP+FN))
- TNR: % flat lands correctly predicted as flat lands (TN/(TN+FP))

- FNR: % steep lands wrongly predicted as flat lands (FN/(TP+FN))
- FPR: % flat lands wrongly predicted as steep lands (FP/(TN+FP))

```
##
## for each stream orders
##

forLoopCounter = 1

for (i in 1:8){
  myOrders <- i # range of 1-8

  data_filtered %>%
    filter(condition_met) %>%
    filter(seg_StreamOrde %in% myOrders)  %>%
    select(rec_meanSlope,seg_StreamOrde) -> this_data_met

  this_quantile_met <- quantile(this_data_met[,1],c(1:1000)/1000)

  this_quantile_met <- as.data.frame(cbind(seq(1,1000,1)/10,this_quantile_met
))
  colnames(this_quantile_met) <- c("quantile","rec_meanSlope")
  this_quantile_met$buf_condition <- "met"
  this_quantile_met$seg_StreamOrde <- i

  ##
  ## conditions unmet (either side was greater than 10 degrees)
  ##

  data_filtered %>%
    filter(!condition_met) %>%
    filter(seg_StreamOrde %in% myOrders)  %>%
    select(rec_meanSlope,seg_StreamOrde) -> this_data_unmet

  this_quantile_unmet <- quantile(this_data_unmet[,1],c(1:1000)/1000)

  this_quantile_unmet <-  as.data.frame(cbind(seq(1,1000,1)/10,this_quantile_
unmet))
  colnames(this_quantile_unmet) <- c("quantile","rec_meanSlope")
  this_quantile_unmet$buf_condition <- "unmet"
  this_quantile_unmet$seg_StreamOrde <- i

  if (forLoopCounter == 1){
    bufCondition_REC_quantile <- rbind(this_quantile_met, this_quantile_unmet
)
  } else {
    bufCondition_REC_quantile <- rbind(bufCondition_REC_quantile, this_quanti
le_met, this_quantile_unmet)
```

```
  }

  forLoopCounter = forLoopCounter + 1

}

##
## hist plot
##

ggplot() +
  geom_histogram(
    data = data_conditioned,
    mapping = aes(x = rec_meanSlope,
                  y = ..ncount..,
                  color = buf_condition),
    binwidth = 1,
    fill = NA,
    alpha = 0.5,
    position="identity"
  ) +
  labs(
    x = "REC mean slope (degree)",
    y = "Number of REC"
  ) +
  facet_wrap(. ~ seg_StreamOrde,
             ncol = 2)
```

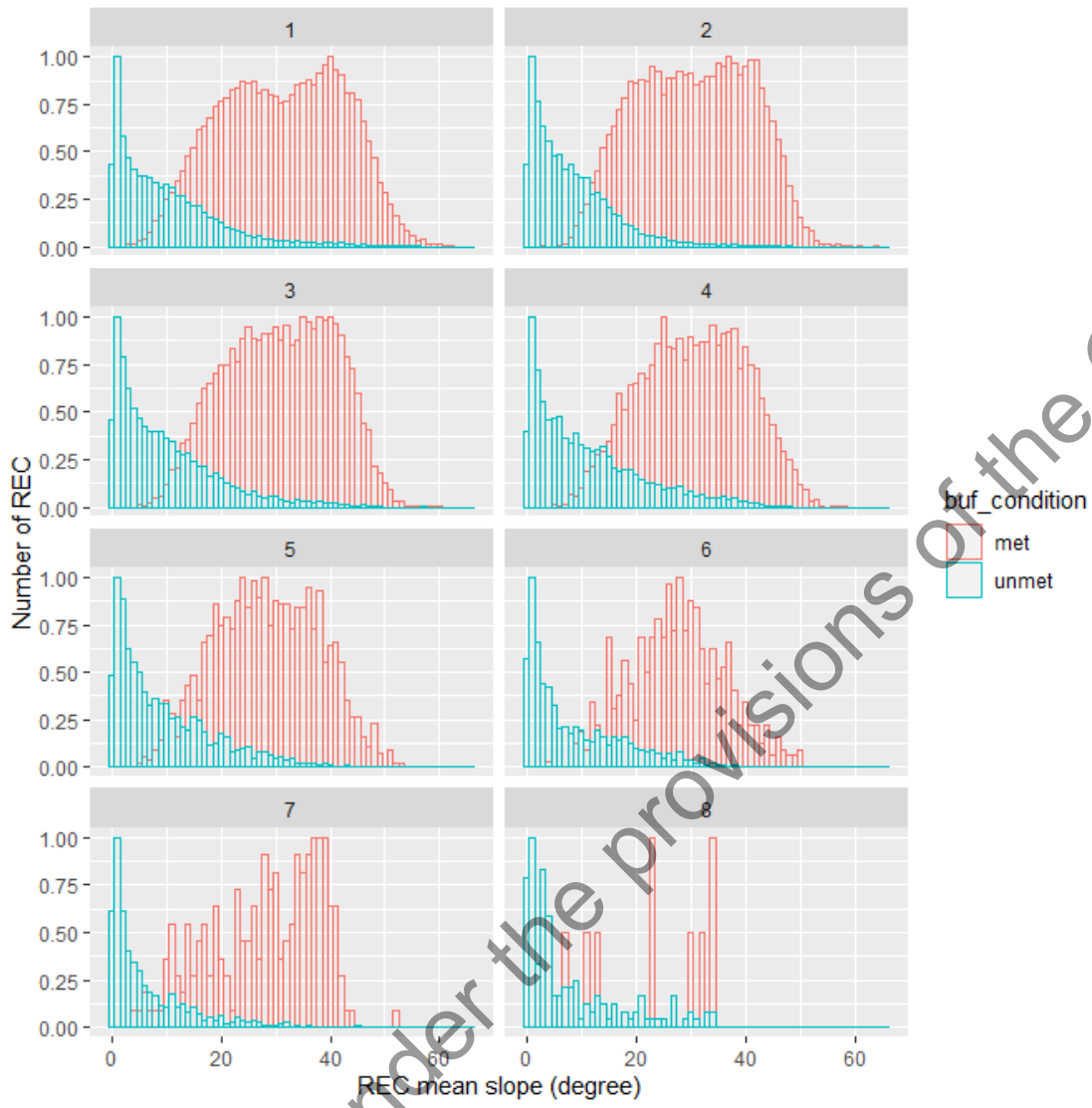


Figure. Distribution of the REC segments met (no exclusion requirement) and unmet (exclusion requirement) the steep land definition; scaled to 1, and note that different stream orders were analysed independently.


```
##
## percentile plot
##

ggplot() +
  geom_line(data = bufCondition_REC_quantile,
            mapping = aes(y = quantile,
                          x = rec_meanSlope,
                          color = buf_condition),
            size = 1
```

```
  ) +
  labs(
    x = "REC mean slope (degree)",
    y = "Quantile (%)"
  ) +
  facet_wrap(. ~ seg_StreamOrde,
             ncol = 2)
```

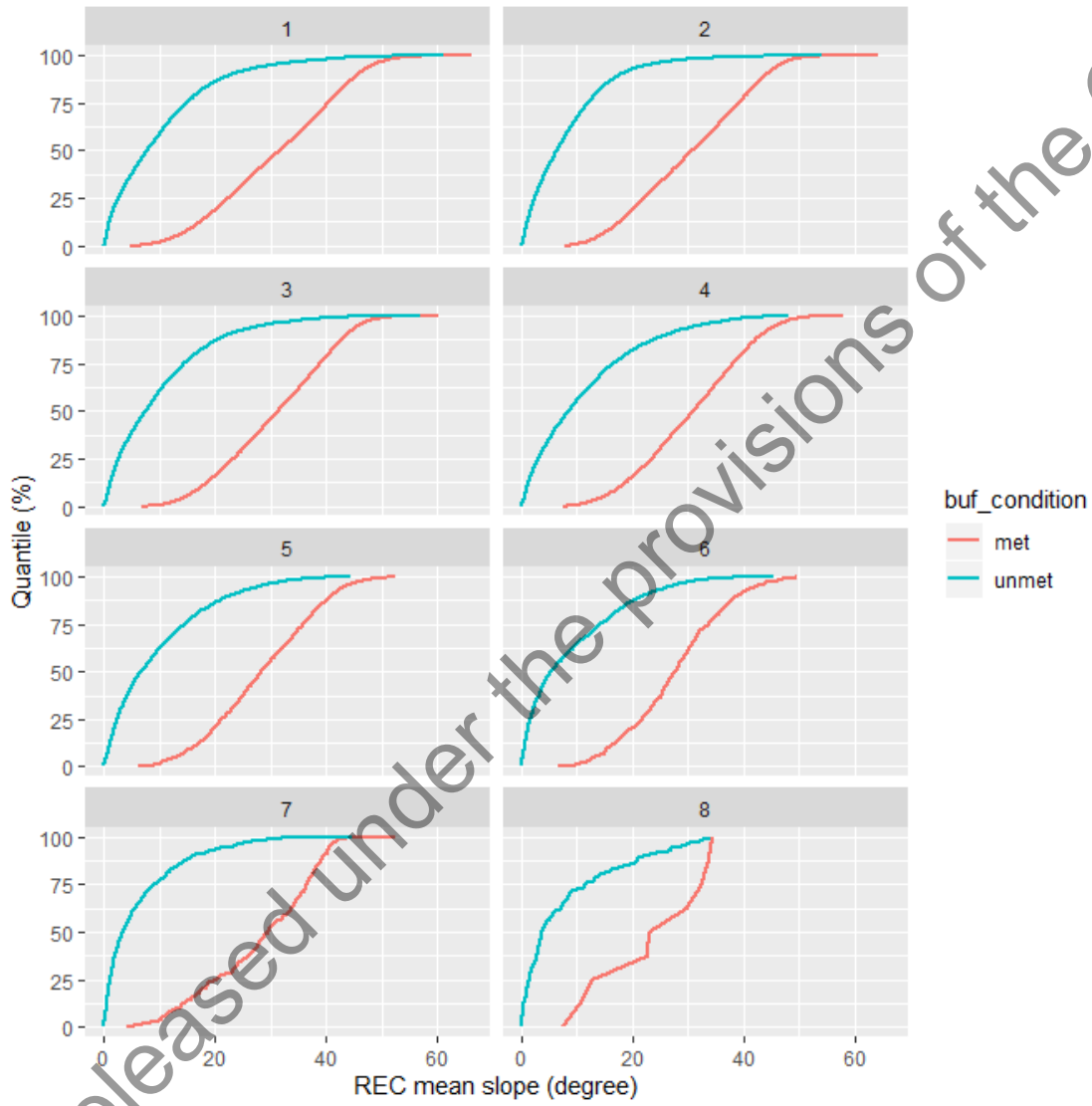


Figure. Cumulative proportion of the REC segments that met (no exclusion) and unmet (exclusion requirement) the steep land definition. Each river order was analysed independently.