Tear-down approach

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Below is the tear-down approach for the CA dataset. All variables were initially included, and based on their significance they were slowly removed from the model to improve fit.

The null model was estimated as:

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula: delta_tvp ~ 1 + (1 | HUC12)
##    Data: data
##
##      AIC      BIC   logLik deviance df.resid
## -25202.1 -25175.2  12604.0 -25208.1    56775
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0219 -0.3672 -0.0123  0.3519  5.2901
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  HUC12    (Intercept) 0.00211  0.04593
##  Residual             0.03743  0.19347
## Number of obs: 56778, groups:  HUC12, 56
##
## Fixed effects:
##              Estimate Std. Error t value
## (Intercept) -0.062427   0.006487  -9.624
```

And the ICC for the null model was found to be 0.0533592. The results from a GLM model show high significance due to the large sample size:

```
##
## Call:
## glm(formula = delta_tvp ~ delta_lc + diverse + Avg_WSEL_5yrChange +
##     WR_density + Perc_Rip + Perc_Pre1914 + GW_dnsty15, data = ds)
##
## Deviance Residuals:
##      Min        1Q    Median        3Q       Max
## -1.19482  -0.07798  -0.00389   0.06986   1.03173
##
## Coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)        -0.1309511  0.0040292 -32.501  < 2e-16 ***
## delta_lc            0.0072175  0.0017380   4.153 3.29e-05 ***
## diverse             0.0219983  0.0026135   8.417  < 2e-16 ***
## Avg_WSEL_5yrChange -0.0010032  0.0001678  -5.978 2.27e-09 ***
## WR_density          0.0010692  0.0004656   2.297   0.0216 *
## Perc_Rip            0.0207509  0.0070834   2.929   0.0034 **
## Perc_Pre1914       -0.0097268  0.0074626  -1.303   0.1924
## GW_dnsty15          0.2348366  0.0236895   9.913  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## (Dispersion parameter for gaussian family taken to be 0.03882261)
##
##     Null deviance: 2220.1  on 56441  degrees of freedom
## Residual deviance: 2190.9  on 56434  degrees of freedom
##   (350 observations deleted due to missingness)
## AIC: -23181
##
## Number of Fisher Scoring iterations: 2
```

Our first multi-level model includes all of the predictor variables as well as interaction terms between the i-level variable, a land-use flag, and group-level factors. The idea here is that land use changes could interact with HUC-level dynamics, such as the density of water rights and groundwater use. We also allow the effects of the i-level variable, `delta_lc`, to vary across groups.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula:
## delta_tvp ~ delta_lc + diverse + Avg_WSEL_5yrChange + WR_density +
##     Perc_Rip + Perc_Pre1914 + GW_dnsty15 + delta_lc * diverse +
##     delta_lc * WR_density + delta_lc * GW_dnsty15 + (1 + delta_lc |
##     HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -25068.6 -24934.5  12549.3 -25098.6    56427
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0881 -0.3658 -0.0108  0.3523  5.2668
##
## Random effects:
##  Groups   Name        Variance  Std.Dev. Corr
##  HUC12    (Intercept) 0.0021046 0.04588
##           delta_lc    0.0009087 0.03014  -0.30
##  Residual             0.0373537 0.19327
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                        Estimate Std. Error t value
## (Intercept)         -0.1105315  0.0270924  -4.080
## delta_lc             0.0457640  0.0174318   2.625
## diverse              0.0106104  0.0167872   0.632
## Avg_WSEL_5yrChange  -0.0006176  0.0012726  -0.485
## WR_density          -0.0007497  0.0010192  -0.736
## Perc_Rip             0.0340319  0.0358543   0.949
## Perc_Pre1914        -0.0116607  0.0423934  -0.275
## GW_dnsty15           0.3809016  0.1632130   2.334
## delta_lc:diverse    -0.0186626  0.0091781  -2.033
## delta_lc:WR_density  0.0012540  0.0010991   1.141
## delta_lc:GW_dnsty15 -0.1423372  0.0981022  -1.451
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc divers A_WSEL WR_dns Prc_Rp P_P191 GW_d15 dlt_l:
## delta_lc    -0.271
## diverse     -0.859  0.215
## Avg_WSEL_5C  0.407 -0.005 -0.250
## WR_density  -0.116  0.023  0.099 -0.068
```

```
## Perc_Rip    -0.265  0.041  0.089 -0.058 -0.007
## Perc_Pr1914  0.401 -0.036 -0.480  0.084 -0.090 -0.773
## GW_dnsty15   0.379 -0.059 -0.638  0.179 -0.017 -0.124  0.408
## dlt_lc:dvrs  0.253 -0.927 -0.238  0.004  0.036 -0.035  0.030  0.130
## dlt_lc:WR_d  0.022 -0.043  0.004  0.010 -0.791  0.014  0.000 -0.027 -0.037
## dlt_l:GW_15 -0.055  0.187  0.111 -0.004 -0.063  0.002  0.001 -0.292 -0.433
##             d_:WR_
## delta_lc
## diverse
## Avg_WSEL_5C
## WR_density
## Perc_Rip
## Perc_Pr1914
## GW_dnsty15
## dlt_lc:dvrs
## dlt_lc:WR_d
## dlt_l:GW_15  0.088
```

We calculate the deviance for each model, which is a measure of model fit. We compare the deviance of the more complex model (`M1`) to less complex models progressively to see if dropping parameters improves fit. Since we are typically changing only one degree of freedom, we are looking fofr changes in deviance that are above ~3.8.

```
devcomp = getME(M1,"devcomp")
devM1 = as.numeric(devcomp$cmp[8])
```

The deviance for the full model is `devM1`. The results of `M1` suggest that `Perc_pre1914` is not significant. In `M2` we drop this variable from the analysis:

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula:
## delta_tvp ~ delta_lc + diverse + Avg_WSEL_5yrChange + WR_density +
##     Perc_Rip + GW_dnsty15 + delta_lc * diverse + delta_lc * WR_density +
##     delta_lc * GW_dnsty15 + (1 + delta_lc | HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -25070.6 -24945.4  12549.3 -25098.6    56428
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0881 -0.3658 -0.0108  0.3523  5.2667
##
## Random effects:
##  Groups   Name        Variance  Std.Dev. Corr
##  HUC12    (Intercept) 0.0021127 0.04596
##           delta_lc    0.0009081 0.03014  -0.30
##  Residual             0.0373537 0.19327
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                         Estimate Std. Error t value
## (Intercept)          -0.1075262  0.0248617  -4.325
## delta_lc              0.0455607  0.0174157   2.616
## diverse               0.0083724  0.0147460   0.568
## Avg_WSEL_5yrChange   -0.0005888  0.0012695  -0.464
## WR_density           -0.0007759  0.0010153  -0.764
```

```
## Perc_Rip             0.0264626  0.0227840   1.161
## GW_dnsty15           0.3992803  0.1492384   2.675
## delta_lc:diverse    -0.0185776  0.0091715  -2.026
## delta_lc:WR_density  0.0012548  0.0010991   1.142
## delta_lc:GW_dnsty15 -0.1422584  0.0980782  -1.450
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc divers A_WSEL WR_dns Prc_Rp GW_d15 dlt_l: d_:WR_
## delta_lc    -0.281
## diverse     -0.830  0.226
## Avg_WSEL_5C  0.409 -0.002 -0.240
## WR_density  -0.088  0.020  0.064 -0.061
## Perc_Rip     0.077  0.020 -0.506  0.011 -0.121
## GW_dnsty15   0.258 -0.049 -0.552  0.159  0.022  0.331
## dlt_lc:dvrs  0.265 -0.927 -0.256  0.001  0.039 -0.019  0.130
## dlt_lc:WR_d  0.024 -0.043  0.004  0.010 -0.794  0.022 -0.030 -0.037
## dlt_l:GW_15 -0.061  0.187  0.128 -0.004 -0.064  0.004 -0.322 -0.434  0.088
```

Then we calculate the deviance and compare it to `M1`.

The change in deviance is `devstat`. This deviance vale isn't significant, so let's keep `Perc_Pre1914` in the model for now. In `M3` we drop `Avg_WSEL_5yrChange` due to low significance. We compare the deviance of this model to the original full model.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula:
## delta_tvp ~ delta_lc + diverse + WR_density + Perc_Rip + GW_dnsty15 +
##     Perc_Pre1914 + delta_lc * diverse + delta_lc * WR_density +
##     delta_lc * GW_dnsty15 + (1 + delta_lc | HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -25070.4 -24945.2  12549.2 -25098.4    56428
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0880 -0.3657 -0.0108  0.3523  5.2667
##
## Random effects:
##  Groups   Name        Variance  Std.Dev. Corr
##  HUC12    (Intercept) 0.0021171 0.04601
##           delta_lc    0.0009075 0.03012  -0.30
##  Residual             0.0373536 0.19327
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                       Estimate Std. Error t value
## (Intercept)         -0.1051688  0.0248170  -4.238
## delta_lc             0.0457682  0.0174235   2.627
## diverse              0.0085888  0.0163105   0.527
## WR_density          -0.0007836  0.0010174  -0.770
## Perc_Rip             0.0330204  0.0359189   0.919
## GW_dnsty15           0.3948547  0.1610823   2.451
## Perc_Pre1914        -0.0099735  0.0424039  -0.235
## delta_lc:diverse    -0.0186640  0.0091735  -2.035
## delta_lc:WR_density  0.0012592  0.0010990   1.146
## delta_lc:GW_dnsty15 -0.1425701  0.0980467  -1.454
```

```
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc divers WR_dns Prc_Rp GW_d15 P_P191 dlt_l: d_:WR_
## delta_lc    -0.290
## diverse     -0.856  0.218
## WR_density  -0.097  0.022  0.085
## Perc_Rip    -0.265  0.040  0.078 -0.011
## GW_dnsty15   0.341 -0.059 -0.623 -0.005 -0.115
## Perc_Pr1914  0.403 -0.036 -0.477 -0.085 -0.772  0.402
## dlt_lc:dvrs  0.272 -0.927 -0.241  0.036 -0.034  0.130  0.029
## dlt_lc:WR_d  0.020 -0.043  0.006 -0.791  0.015 -0.029 -0.001 -0.038
## dlt_l:GW_15 -0.058  0.187  0.112 -0.064  0.001 -0.292  0.001 -0.433  0.088
```

```
## [1] 0.2330824
```

Once again the deviance isn't significant, with a value of `devstat`. In `M4` we drop a cross-level interaction from the analysis, `diverse*delta_lc`.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula:
## delta_tvp ~ delta_lc + diverse + WR_density + Perc_Rip + GW_dnsty15 +
##     Perc_Pre1914 + Avg_WSEL_5yrChange + delta_lc * WR_density +
##     delta_lc * GW_dnsty15 + (1 + delta_lc | HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -25066.7 -24941.5  12547.3 -25094.7    56428
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0897 -0.3652 -0.0110  0.3524  5.2659
##
## Random effects:
##  Groups   Name        Variance  Std.Dev. Corr
##  HUC12    (Intercept) 0.0021408 0.04627
##           delta_lc    0.0009997 0.03162  -0.33
##  Residual             0.0373541 0.19327
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                       Estimate Std. Error t value
## (Intercept)         -0.0960181  0.0262039  -3.664
## delta_lc             0.0129066  0.0067799   1.904
## diverse              0.0020871  0.0162829   0.128
## WR_density          -0.0006836  0.0010204  -0.670
## Perc_Rip             0.0315261  0.0358680   0.879
## GW_dnsty15           0.4263008  0.1624902   2.624
## Perc_Pre1914        -0.0088918  0.0423714  -0.210
## Avg_WSEL_5yrChange  -0.0006243  0.0012710  -0.491
## delta_lc:WR_density  0.0011798  0.0011025   1.070
## delta_lc:GW_dnsty15 -0.2288824  0.0919640  -2.489
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc divers WR_dns Prc_Rp GW_d15 P_P191 A_WSEL d_:WR_
## delta_lc    -0.107
## diverse     -0.849 -0.015
```

```
## WR_density  -0.130  0.148  0.110
## Perc_Rip    -0.264  0.024  0.083 -0.006
## GW_dnsty15   0.356  0.177 -0.627 -0.020 -0.119
## Perc_Pr1914  0.406 -0.025 -0.486 -0.090 -0.773  0.405
## Avg_WSEL_5C  0.420 -0.004 -0.256 -0.068 -0.058  0.179  0.085
## dlt_lc:WR_d  0.034 -0.204 -0.005 -0.792  0.013 -0.024  0.000  0.010
## dlt_l:GW_15  0.069 -0.636  0.009 -0.053 -0.017 -0.283  0.017 -0.002  0.079
```

```
## [1] 3.972189
```

This shows a significant change in deviance, with a deviance value of `devstat` so we keep the change. In `M5` we drop the another interaction effect, `delta_lc*WR_density`.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula:
## delta_tvp ~ delta_lc + diverse + WR_density + Perc_Rip + GW_dnsty15 +
##     Perc_Pre1914 + Avg_WSEL_5yrChange + delta_lc * GW_dnsty15 +
##     (1 + delta_lc | HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -25067.5 -24951.3  12546.8 -25093.5    56429
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0896 -0.3651 -0.0110  0.3523  5.2662
##
## Random effects:
##  Groups   Name        Variance  Std.Dev. Corr
##  HUC12    (Intercept) 0.0021238 0.04608
##           delta_lc    0.0009998 0.03162  -0.32
##  Residual             0.0373549 0.19327
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                       Estimate Std. Error t value
## (Intercept)         -0.0972658  0.0261379  -3.721
## delta_lc             0.0144185  0.0066373   2.172
## diverse              0.0023798  0.0162564   0.146
## WR_density           0.0001811  0.0006233   0.291
## Perc_Rip             0.0310443  0.0357894   0.867
## GW_dnsty15           0.4294013  0.1619831   2.651
## Perc_Pre1914        -0.0090791  0.0422938  -0.215
## Avg_WSEL_5yrChange  -0.0006355  0.0012686  -0.501
## delta_lc:GW_dnsty15 -0.2368552  0.0916846  -2.583
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc divers WR_dns Prc_Rp GW_d15 P_P191 A_WSEL
## delta_lc    -0.101
## diverse     -0.850 -0.016
## WR_density  -0.168 -0.025  0.174
## Perc_Rip    -0.265  0.026  0.083  0.007
## GW_dnsty15   0.358  0.173 -0.628 -0.064 -0.119
## Perc_Pr1914  0.406 -0.024 -0.486 -0.147 -0.773  0.406
## Avg_WSEL_5C  0.420 -0.002 -0.256 -0.098 -0.058  0.180  0.084
## dlt_l:GW_15  0.065 -0.635  0.010  0.015 -0.017 -0.278  0.016 -0.003
```

```
## [1] 1.143127
```

The deviance value is `devstat`, which suggest this change was not significant. We'll keep `delta_lc*WR_density` for now. Let's try dropping the other interaction term, `delta_lc*GW_dnsty15`.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula:
## delta_tvp ~ delta_lc + diverse + WR_density + Perc_Rip + GW_dnsty15 +
##     Perc_Pre1914 + Avg_WSEL_5yrChange + delta_lc * WR_density +
##     (1 + delta_lc | HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -25062.8 -24946.6  12544.4 -25088.8    56429
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0896 -0.3652 -0.0109  0.3524  5.2679
##
## Random effects:
##  Groups   Name        Variance Std.Dev. Corr
##  HUC12    (Intercept) 0.002208 0.04699
##           delta_lc    0.001148 0.03389  -0.37
##  Residual             0.037354 0.19327
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                       Estimate Std. Error t value
## (Intercept)         -0.0906206  0.0261851  -3.461
## delta_lc             0.0022423  0.0055455   0.404
## diverse              0.0019500  0.0162879   0.120
## WR_density          -0.0008233  0.0010221  -0.805
## Perc_Rip             0.0301059  0.0359905   0.836
## GW_dnsty15           0.3094861  0.1558339   1.986
## Perc_Pre1914        -0.0069055  0.0424549  -0.163
## Avg_WSEL_5yrChange  -0.0006514  0.0012717  -0.512
## delta_lc:WR_density  0.0013960  0.0011055   1.263
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc divers WR_dns Prc_Rp GW_d15 P_P191 A_WSEL
## delta_lc    -0.093
## diverse     -0.851 -0.012
## WR_density  -0.127  0.144  0.110
## Perc_Rip    -0.262  0.019  0.082 -0.007
## GW_dnsty15   0.391 -0.005 -0.651 -0.037 -0.129
## Perc_Pr1914  0.404 -0.020 -0.484 -0.088 -0.774  0.427
## Avg_WSEL_5C  0.420 -0.006 -0.256 -0.067 -0.059  0.186  0.085
## dlt_lc:WR_d  0.029 -0.195 -0.005 -0.793  0.014 -0.002 -0.002  0.009
```

```
## [1] 4.70367
```

The deviance value is high, with a value of `devstat`, so we keep the change. We'll try dropping `diverse`, which has very low signficance.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
```

```
## Formula:
## delta_tvp ~ delta_lc + WR_density + Perc_Rip + GW_dnsty15 + Perc_Pre1914 +
##     Avg_WSEL_5yrChange + delta_lc * WR_density + (1 + delta_lc |
##     HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -25064.8 -24957.5  12544.4 -25088.8    56430
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.0896 -0.3652 -0.0109  0.3524  5.2679
##
## Random effects:
##  Groups   Name        Variance Std.Dev. Corr
##  HUC12    (Intercept) 0.002219 0.04711
##           delta_lc    0.001148 0.03388  -0.37
##  Residual             0.037354 0.19327
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                       Estimate Std. Error t value
## (Intercept)         -0.0878773  0.0137638  -6.385
## delta_lc             0.0022339  0.0055439   0.403
## WR_density          -0.0008380  0.0010163  -0.825
## Perc_Rip             0.0297462  0.0359105   0.828
## GW_dnsty15           0.3201022  0.1184255   2.703
## Perc_Pre1914        -0.0044828  0.0371855  -0.121
## Avg_WSEL_5yrChange  -0.0006175  0.0012301  -0.502
## delta_lc:WR_density  0.0013980  0.0011055   1.265
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc WR_dns Prc_Rp GW_d15 P_P191 A_WSEL
## delta_lc    -0.199
## WR_density  -0.063  0.147
## Perc_Rip    -0.368  0.021 -0.016
## GW_dnsty15  -0.407 -0.018  0.046 -0.101
## Perc_Pr1914 -0.017 -0.030 -0.040 -0.843  0.169
## Avg_WSEL_5C  0.398 -0.009 -0.040 -0.040  0.026 -0.046
## dlt_lc:WR_d  0.048 -0.195 -0.797  0.015 -0.007 -0.005  0.008
```

```
## [1] 0.01329653
```

The change in deviance was tiny at `devstat`, so no point dropping this variable. Just to play, I'll drop the variation in the slope of the effect of `delta_lc` across groups.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula:
## delta_tvp ~ delta_lc + WR_density + Perc_Rip + GW_dnsty15 + Perc_Pre1914 +
##     Avg_WSEL_5yrChange + delta_lc * WR_density + (1 | HUC12)
##    Data: ds
##
##      AIC      BIC   logLik deviance df.resid
## -24835.6 -24746.2  12427.8 -24855.6    56432
##
## Scaled residuals:
```

```
##     Min      1Q  Median      3Q     Max
## -6.0150 -0.3674 -0.0114  0.3518  5.2655
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  HUC12    (Intercept) 0.001775 0.04213
##  Residual             0.037575 0.19384
## Number of obs: 56442, groups:  HUC12, 49
##
## Fixed effects:
##                       Estimate Std. Error t value
## (Intercept)         -0.0881552  0.0130129  -6.774
## delta_lc             0.0006421  0.0019225   0.334
## WR_density          -0.0014718  0.0009524  -1.545
## Perc_Rip             0.0261713  0.0342208   0.765
## GW_dnsty15           0.3228342  0.1139668   2.833
## Perc_Pre1914         0.0017482  0.0354675   0.049
## Avg_WSEL_5yrChange  -0.0001951  0.0011829  -0.165
## delta_lc:WR_density  0.0022450  0.0009865   2.276
##
## Correlation of Fixed Effects:
##             (Intr) dlt_lc WR_dns Prc_Rp GW_d15 P_P191 A_WSEL
## delta_lc    -0.063
## WR_density  -0.056  0.330
## Perc_Rip    -0.372  0.001 -0.016
## GW_dnsty15  -0.418 -0.021  0.044 -0.096
## Perc_Pr1914 -0.025 -0.016 -0.043 -0.839  0.164
## Avg_WSEL_5C  0.405 -0.017 -0.043 -0.035  0.024 -0.052
## dlt_lc:WR_d  0.036 -0.429 -0.775  0.015 -0.002 -0.005  0.010
```

```
## [1] 233.2408
```

Ok, this is a crazy massively high change in deviance, so I'll definitely keep the change. The deviance was `devstat`. Is this possible? The size and significance of the intercept remains large, suggesting we should think about additional variables to include. Controling for the effects of the drought will certainly help. This final model, however, suggests that the density of groundwater use and water rights have significant effects on total vegetation production. Interestingly, water right density has a negative effect (need to work on interpretation here of `delta_tvp`). Groundwater density has a HUGE positive effect. The interation between land use and water rights density has a significant positive effect.. suggesting that both a change in land-use and dense water rights increased total vegetative production.