Predicting hydraulic head levels with machine learning

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Introduction: Hydrologic Cycle

- Precipitation infiltrates as recharge
- Aquifer: lens-shaped fresh water body
- Dikes can withhold groundwater

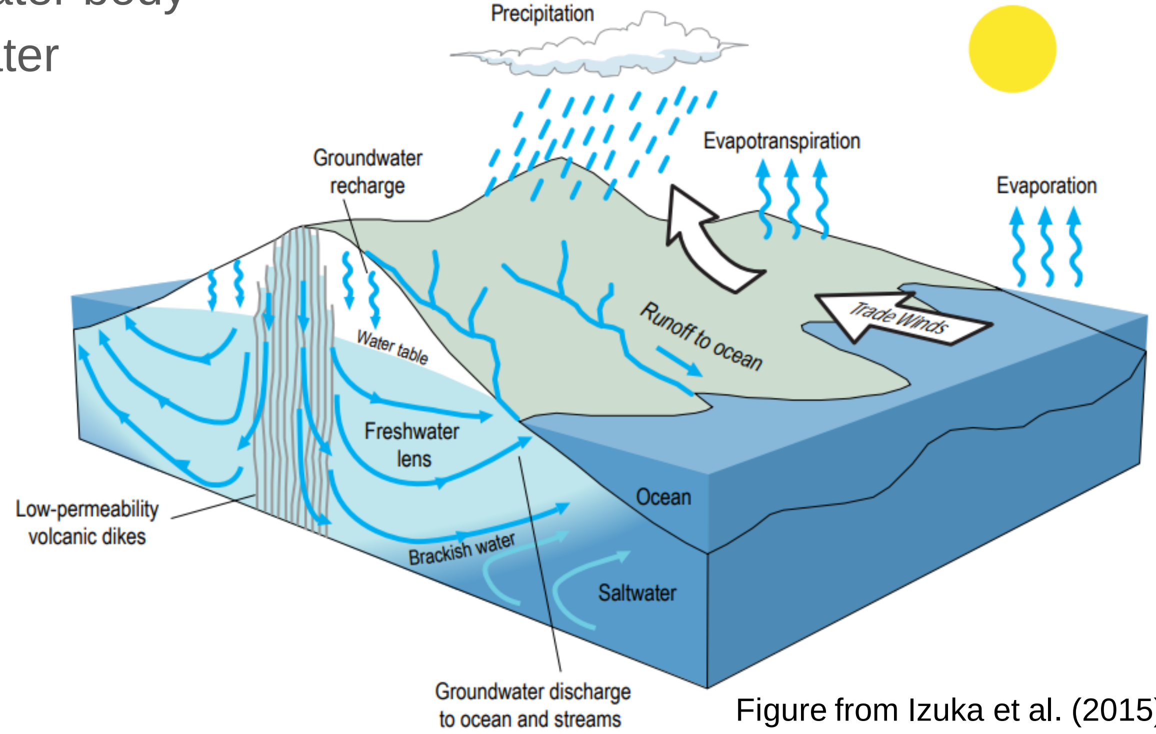


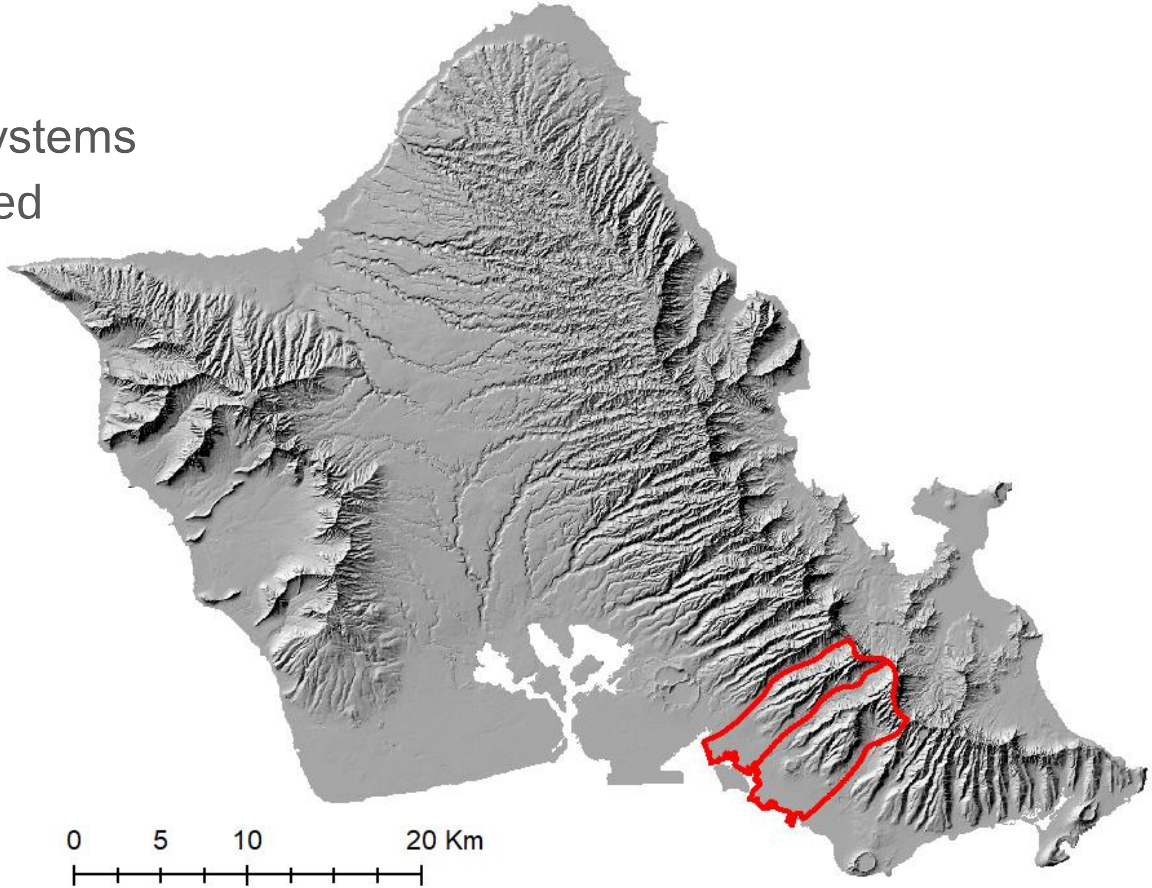
Figure from Izuka et al. (2015)

Motivation

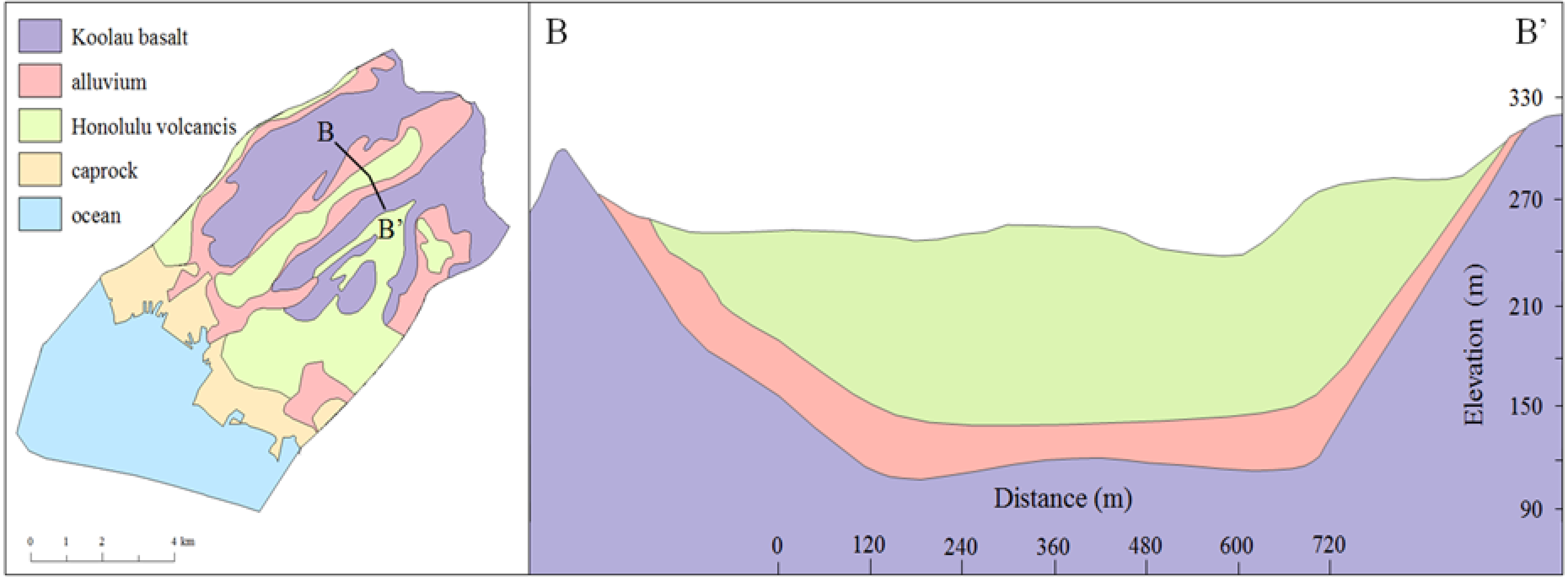
- O‘ahu has a large population which requires a large quantity of water
- Groundwater is primary source of Hawaii’s fresh water
- It’s important to know how much water is available for pumping
- Therefore, it’s important to understand how the hydrogeology controls groundwater flow and storage

Study Site

- Nu‘uanu and Kalihi aquifer systems
- Part of the Honolulu watershed

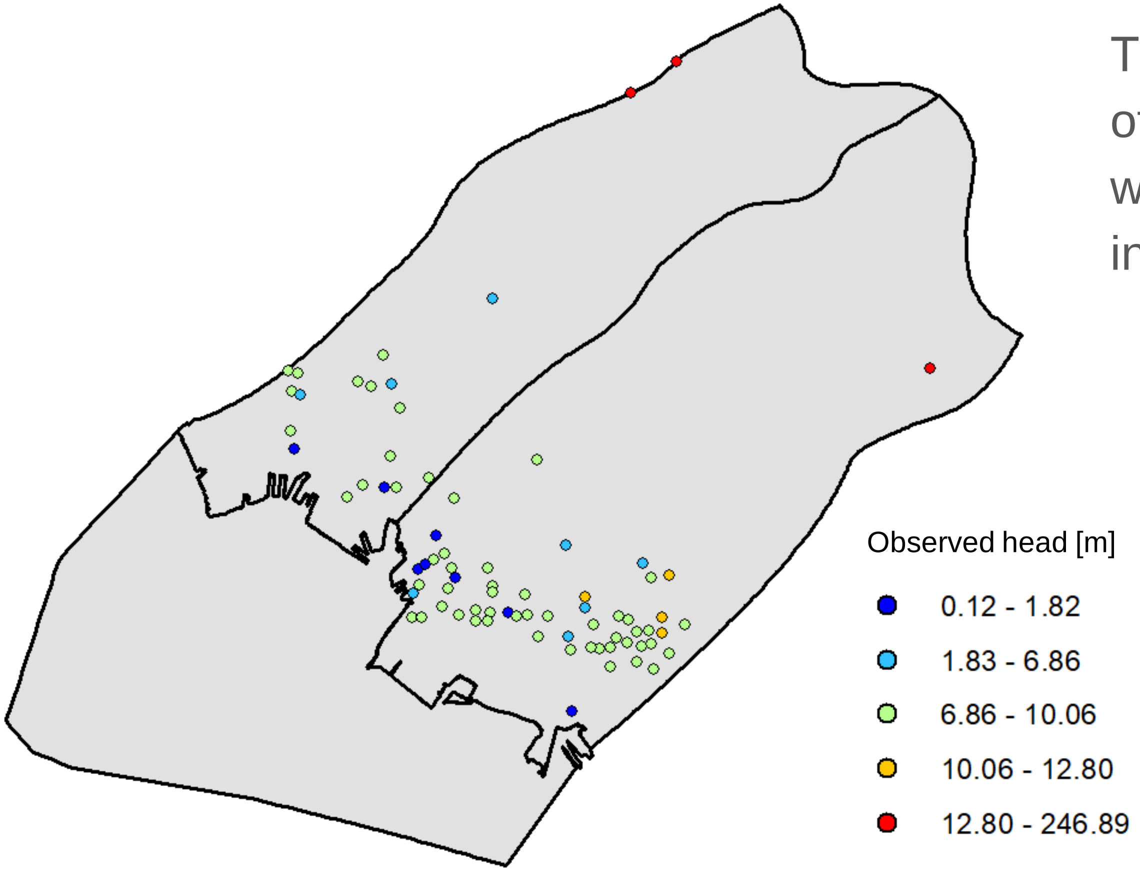


Complex Hydrogeology



Figures interpreted from Sherrod et al. (2007) and Wentworth (1941)

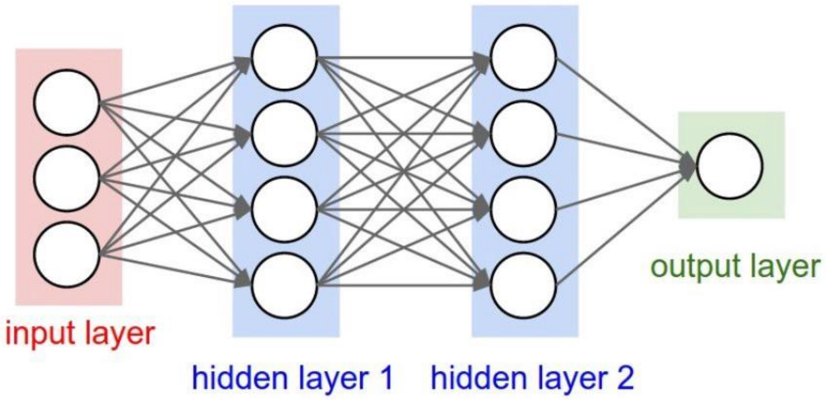
Limited Monitoring/Pumping Wells



There's a poor spatial distribution of monitoring and/or pumping wells, which reduces confidence in model calibration.

Methods Overview

- Develop simple 3D model in GMS using MODFLOW (http://www.aquaveo.com)
- Utilize FloPy (Bakker et al., 2019) to read model files using python
- Simulate different hydraulic conductivity scenarios to yield different synthetic hydraulic head results
- Use the scenario results to train a DNN model to predict hydraulic heads



Neural Network
(image credit: http://cs231n.github.io/neural-networks-1/)

Random hydraulic conductivity scenarios

```
result_array = []
iterations = range(501)

for i in iterations:
  mf_object = flopy.modflow.Modflow.load('Nuuanu_v2_take1.mfn',exe_name=exe_name,verbose=True,
  check=True,forgive=False)
  temp_hk = mf_object.lpf.hk.array

  # loop over every iteration and assign random values to each hk zone
  hkz1 = random.randint(10,40); temp_hk[:,:,0:50] = hkz1
  hkz2 = random.randint(100,200); temp_hk[:,:,50:65] = hkz2
  hkz3 = random.randint(500,1000); temp_hk[:,:,65:100] = hkz3
  hkz4 = random.randint(1,10); temp_hk[:,:,100:120] = hkz4

  # assign temp_hk to lpf.hk
  mf_object.lpf.hk = temp_hk
  mf_object.write_input()
  success, buff = mf_object.run_model()
  layer=2
```

Assign the number of scenarios you want to run

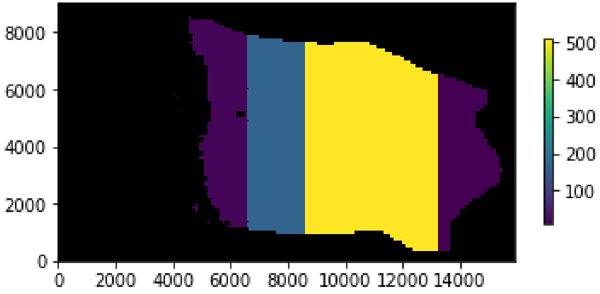
Initiate GMS MODFLOW file

Randomly assign HK values

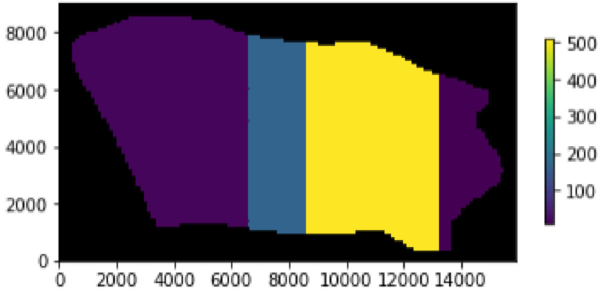
Example Output

HK zone 1 = 15 m/d
HK zone 2 = 169 m/d
HK zone 3 = 509 m/d
HK zone 4 = 9 m/d

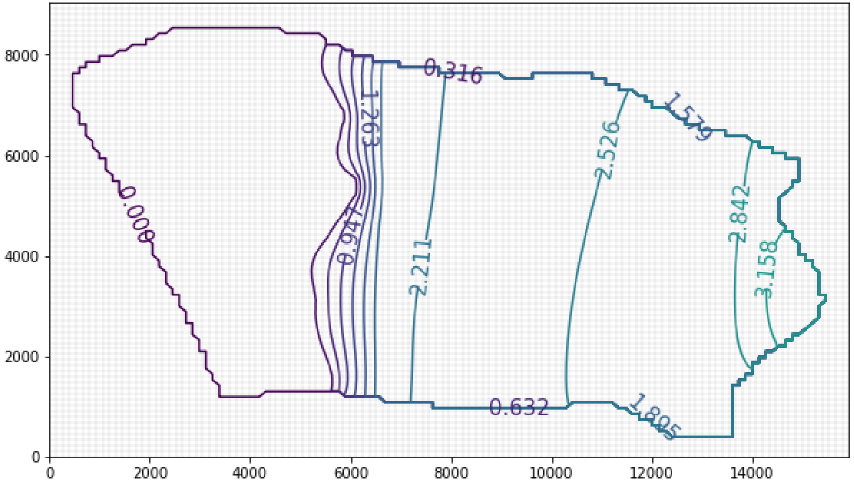
hk layer 1



hk layer 2-5

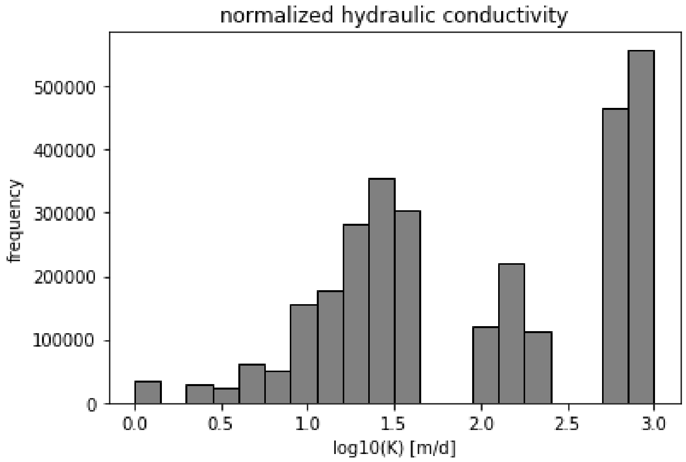


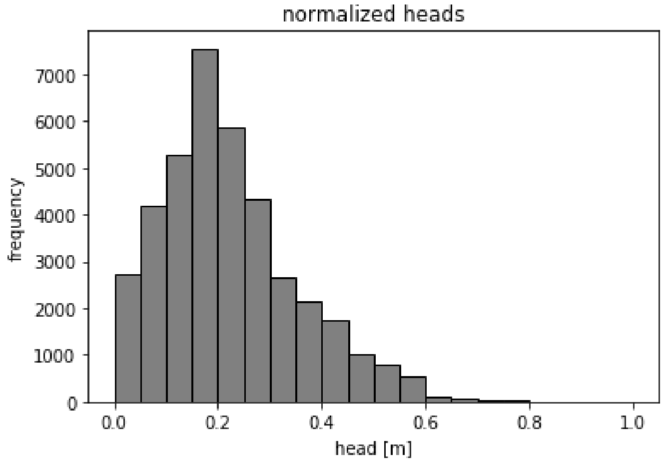
Resulting head contours [m]



Normalize the data

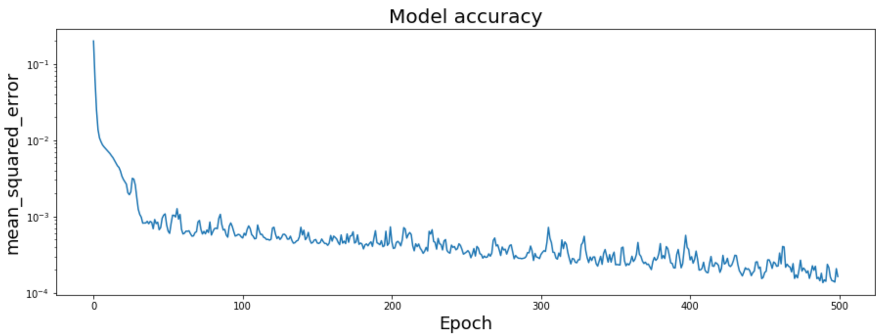
```
x_train = np.zeros((501, 5881)); y_train = np.zeros((501, 78))
for i in range(501):
  hk_training = np.loadtxt('hk_dist_%d.txt'%(i))
  head_training = np.loadtxt('sim_heads_dist_%d.txt'%(i))
  x_train[i,:] = hk_training; y_train[i,:] = head_training

x_train_log = np.log10(x_train)
y_train_min = y_train.min()
y_train_max = y_train.max()
y_train_norm = (y_train-y_train_min)/(y_train_max-y_train_min)
```

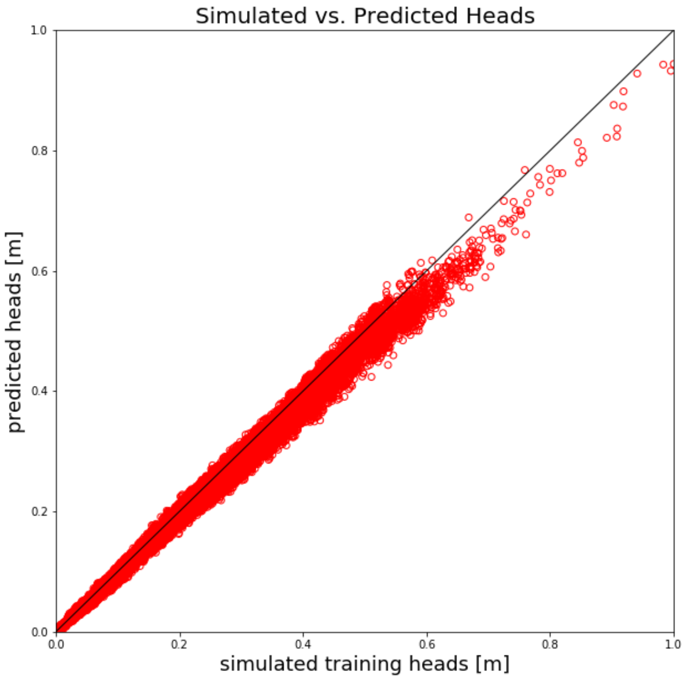




Training DNN Model

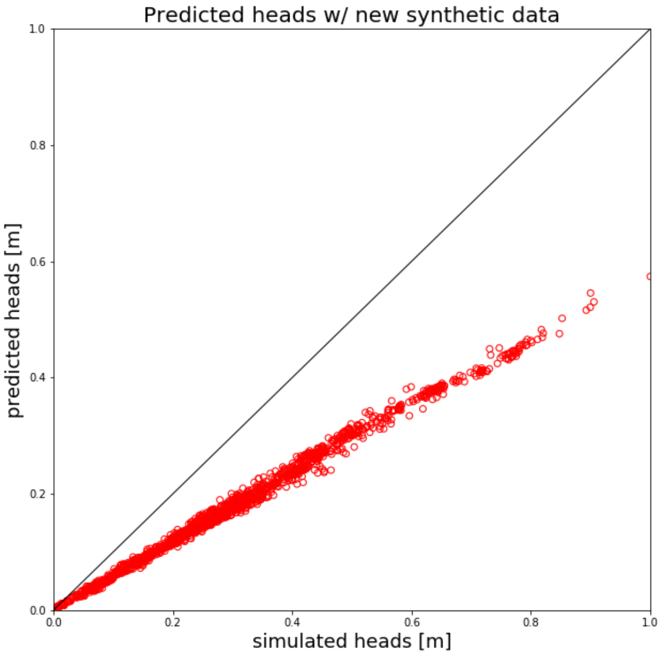
```
model = Sequential()
model = tf.keras.Sequential()
model.add(Dense(64,activation=relu,input_shape=(5881,)))
model.add(Dense(64,activation=relu))
model.add(Dense(64,activation=relu))
model.add(Dense(64,activation=sigmoid))
model.add(Dense(78))
model.compile(optimizer='adam',
      loss='mean_squared_error',
      metrics=['mse'])
.
.
history = model.fit(x_train_log, y_train_norm,
      epochs=500, validation_data=None,
      batch_size = 64)
.
.
y_pred = model.predict(x_train_log)
```





Future Work

- Simulate a more complex hydrogeology within FloPy
- Calibrate the model with measured head levels rather than synthetic heads
- Apply the DNN model to new test data
- Extend to a CNN model



References

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