rainfall_flood

December 14, 2022

0.0.1 Importing necessary packages

[1]:
```
import numpy as np
import random
import matplotlib.pyplot as plt
import scipy.stats as sts
import pandas as pd
```

0.0.2 Data preparation

A rainfall study divided Pakistan into 5 zones (Salma et.al., 2012) based on rainfall trends. The main essence of this division is latitude. I have taken 5 cities from each of the zones to design the CA model with the 5 cities forming one row of the final grid.

[2]:
```
# names of all the cities
names = ['Swat', 'Skardu', 'Kohistan', 'Gilgit', 'Muzaffarabad', 'Swabi',␣
 ↪'Mianwali', 'Gujrat', 'Nowshera',
         'Jhelum', 'TTK', 'Chiniot', 'Lahore', 'Bhakkar', 'Jhang', 'Lodhran',␣
 ↪'Muzaffargarh', 'Multan', 'DGK',
         'Bahawalpur', 'Karachi', 'Sukkur', 'Larkana', 'Nawabshah', 'Kashmore']
# respective altitudes of the cities
altitudes = [980, 2228, 1650, 1500, 737, 340, 210, 1110, 552, 234, 149, 179,␣
 ↪217, 159, 158, 106, 123, 122, 390, 118,
            10, 67, 147, 34, 66]
# average rain fall per annum
precipitation = [0.67]*5 + [0.65]*5 + [0.33]*5 + [0.22]*5 + [0.29]*5
# percentage of days it rains on average in respective cities
percentage_days = [50]*2 + [45, 50, 45] + [30]*5 + [20]*5 + [10]*5 + [15]*5
# average rainfall per rain
height_per_rain = [precipitation[i]/(60*(percentage_days[i]/100)) for i in␣
 ↪range(len(precipitation))]
# whether soil is waterlogged or not
soil = [0,0,1] + [0]*3 + [1]*4 + [0,1,0,0,0]*2 + [1]*2 + [0]*3
# all cities start off as not flooded
flooded = [False]*25
# does the city have a water body nearby to act as natural drainage
water_body = [0]*5 + [1]*18 + [0,0]
barrage = [0]*25
```

```python
data = pd.DataFrame({
    'Names': names,
    'Altitude in meters': altitudes,
    'Annual Precipitation in meters': precipitation,
    'Rainy days as %age': percentage_days,
    'Average Rainfall in meters': height_per_rain,
    'Soil': soil,
    'Flooded': flooded,
    'Water Body present?': water_body,
    'Barrage': barrage
})
data
```

[2]:

```
           Names  Altitude in meters  Annual Precipitation in meters  \
0           Swat                 980                            0.67
1         Skardu                2228                            0.67
2       Kohistan                1650                            0.67
3         Gilgit                1500                            0.67
4    Muzaffarabad                737                            0.67
5          Swabi                 340                            0.65
6       Mianwali                 210                            0.65
7         Gujrat                1110                            0.65
8       Nowshera                 552                            0.65
9         Jhelum                 234                            0.65
10           TTK                 149                            0.33
11       Chiniot                 179                            0.33
12        Lahore                 217                            0.33
13       Bhakkar                 159                            0.33
14         Jhang                 158                            0.33
15       Lodhran                 106                            0.22
16   Muzaffargarh                123                            0.22
17        Multan                 122                            0.22
18           DGK                 390                            0.22
19    Bahawalpur                 118                            0.22
20       Karachi                  10                            0.29
21        Sukkur                  67                            0.29
22       Larkana                 147                            0.29
23     Nawabshah                  34                            0.29
24      Kashmore                  66                            0.29

    Rainy days as %age  Average Rainfall in meters  Soil  Flooded  \
0                   50                    0.022333     0    False
1                   50                    0.022333     0    False
2                   45                    0.024815     1    False
3                   50                    0.022333     0    False
4                   45                    0.024815     0    False
```

5	30	0.036111	0	False
6	30	0.036111	1	False
7	30	0.036111	1	False
8	30	0.036111	1	False
9	30	0.036111	1	False
10	20	0.027500	0	False
11	20	0.027500	1	False
12	20	0.027500	0	False
13	20	0.027500	0	False
14	20	0.027500	0	False
15	10	0.036667	0	False
16	10	0.036667	1	False
17	10	0.036667	0	False
18	10	0.036667	0	False
19	10	0.036667	0	False
20	15	0.032222	1	False
21	15	0.032222	1	False
22	15	0.032222	0	False
23	15	0.032222	0	False
24	15	0.032222	0	False

	Water Body present?	Barrage
0	0	0
1	0	0
2	0	0
3	0	0
4	0	0
5	1	0
6	1	0
7	1	0
8	1	0
9	1	0
10	1	0
11	1	0
12	1	0
13	1	0
14	1	0
15	1	0
16	1	0
17	1	0
18	1	0
19	1	0
20	1	0
21	1	0
22	1	0
23	0	0
24	0	0

[3]:
```python
class Cell:
    '''
    Class to form a cell in the grid

    Attributes
    ----------
        name: str
            Name of the city
        altitude: int
            Altitude above sea level of the city
        precipitation: int
            total rainfall in the city per annum
        rainy_days: int
            Percentage of days in the year the city experiences rainfall
        height_per_rain: float
            millimeters of rain per rainfall on average
        soil: int
            1 if soil is waterlogged, 0 otherwise
        flooded: boolean
            whether the city is flooded or not
        water_body: int
            1 if city has a water body nearby, 0 otherwise
        net_height: float
            Total height of the city depending on the water level of the soil␣
↪as well
        overflow: float
            Excess water that is not absorbed by the soil and needs to be␣
↪drained
        net_rain: float
            Total amount of rain over a period of time
        barrage: int
            1 if the city is protected by a barrage, 0 otherwise

    '''
    def __init__(self, name, altitude, precipitation, percentage_days,␣
↪height_per_rain, soil, flooded, water_body, barrage):
        '''
        Method to make the instance of the class.

        Parameters
        ----------
            name: str
            altitude: int
            precipitation: int
            percentage_days: int
            height_per_rain: float
            soil: int
```

```
            flooded: boolean
            water_body: int
            barrage: int

        Features
        --------
        If the soil is not water-logged, it still has capacity to absorb water␣
↪so we its capacity is to absorb
        1.5 m of water. If the soil is water-logged, it only has a capacity of␣
↪0.5 m of water.
        '''
        self.name = name
        self.water_body = water_body
        self.altitude = altitude
        self.precipitation = precipitation
        self.rainy_days = percentage_days
        self.height_per_rain = height_per_rain
        self.soil = soil
        self.flooded = flooded
        if self.soil == 0:
            self.water = -2
        else:
            self.water = -0.6
        self.net_height = self.altitude + self.water
        self.overflow = 0
        self.net_rain = 0
        self.barrage = barrage

    def update(self, prob):
        '''
        Method to update the water condition within the cell and simulate the␣
↪rain
        '''
        # check whether rain happens given the probability of a rainy day
        if random.random() < self.rainy_days/100:
            # if it is gonna rain, simulate amount of rain through a gamma␣
↪distribution
            # a gamma distribution was chosen because it is defined between 0␣
↪and +inf which
            # is the range of amount of rain
            rain = sts.gamma(self.height_per_rain, 0.3).rvs()
        else:
            rain = 0
        # add rain amount to total rain
        self.net_rain += rain

        # add rain to water levels in the city
```

```python
        self.water += rain
        # if water level has reached ground level, soil is water logged
        if self.water == 0:
            self.soil = 1
        # if water level is above ground level
        elif self.water > 0:
            # how much water is overflowing
            self.overflow += self.water
            # set water level to ground as water overflows
            self.water = 0
            # city is flooded
            self.flooded = True
            # soil is water-logged
            self.soil = 1
            # net height of the city is now altitude + water level +␣
↪overflowing water
            self.net_height = self.altitude + self.water + self.overflow

        else:
            # if soil is not water logged
            if self.soil == 0:
                # water is absorbed into the ground with a 60% probability,␣
↪restoring original levels
                if random.random() < prob:
                    self.water = -2
                # else: water level goes down by 1 mm per day
                elif self.water-0.2 >= -2:
                    self.water -= 0.2
            else:
                # if soil is water logged, 10% chance of being restored to␣
↪original levels
                if random.random() < prob/6:
                    self.water = -0.6
                else:
                    # water level does not change
                    self.water = self.water

    def update_flood(self):
        '''
        Method to update the flood status of the cell
        '''
        # if water level is below ground level, not flooded
        if self.water + self.overflow <= 0:
            self.flooded = False
        # if above ground level, it is flooded
        else:
            self.flooded = True
```

[4]:
```
class Grid:
    '''
    Class for the grid and the simulation

    Attributes
    ----------
        n: int
            Number of rows and columns
        rows: int
            Number of rows in the grid
        columns: int
            Number of columns in the grid
        cells: list
            the grid which contains all the instances of the cells
        prob: float
            probability with which water level restores to its original level
    '''
    def __init__(self, n = 5, drainage_prob = 0.6):
        '''
        Method to initiate the class when it is called

        Parameters
        ----------
            n: int
                default value = 5. Number of rows and columns
            drainage_prob: float
                default value = 0.6. Probability with which old water levels␣
↪are restored.
        '''
        self.n = n
        self.prob = drainage_prob
        self.rows = self.n
        self.columns = self.n
        self.cells = []
        self.flow = []

        # make the grid
        for i in range(n):
            # make an empty row
            row = []
            for j in range(n):
                # make instances for the cells
                cell = self.getCell(names[(i*5)+j], altitudes[(i*5)+j],␣
↪precipitation[(i*5)+j], percentage_days[(i*5)+j],
                              height_per_rain[(i*5)+j], soil[(i*5)+j],␣
↪flooded[(i*5)+j], water_body[(i*5)+j], barrage[(i*5)+j])
                # append the cell to the row
```

```
                row.append(cell)
            # append the row to the grid
            self.cells.append(row)

    def getCell(self, name, altitude, precipitation, percentage_days, height_per_rain, soil, flooded, water_body, barrage):
        '''
        Method to make an instance of a cell

        Parameters
        ----------
            name: str
            altitude: int
            precipitation: int
            percentage_days: int
            height_per_rain: float
            soil: int (0 or 1)
            flooded: boolean
            water_body: int (0 or 1)
            barrage: int (0 or 1)
        '''
        # makes an instance of the Cell class and returns it
        return Cell(name, altitude, precipitation, percentage_days, height_per_rain, soil, flooded, water_body, barrage)

    def getCells(self):
        '''
        Method to return all the cells in the grid
        '''
        return self.cells

    def observe(self, attribute):
        '''
        Method to plot the grid

        Parameters
        ----------
            attribute: str
                the attribute that you want to observe. Can be any one from the attributes of the Cell class.
        '''
        # get all the cells from the grid
        a = self.getCells()
        # make an empty list to flatten the cells
        all_cells = []
        # loop over the grid and append all the cells into a flat array
        for i in range(len(a)):
```

```
            for j in range(len(a)):
                all_cells.append(a[i][j])
        # make an array by retrieving the attribute under consideration for all␣
↪the cells and make a grid again
        attributes = np.array([getattr(all_cells[i], attribute) for i in␣
↪range(len(all_cells))]).reshape(5,5)
        # make the plot
        plt.figure()
        c = plt.imshow(attributes)
        plt.title(str(attribute))
        plt.colorbar(c)
        plt.show()

    def retrieve(self, attribute):
        '''
        Method to retrieve a grid of the specific attribute that we are looking␣
↪for
        '''
        # get all the cells
        a = self.getCells()
        # flatten the grid
        flattened = np.array(a).flatten()
        # retrieve attribute and reshape to form the grid
        attribute_grid = np.array([getattr(flattened[i], attribute) for i in␣
↪range(len(flattened))]).reshape(self.n, self.n)
        return attribute_grid

    def percolation_test(self):
        '''
        Method to check for percolation
        '''

        # set default percolation to be False
        percolation = False
        # loop over each of the columns
        for y in range(self.n):
            # set flow to be True by default
            flow = True
            # retrieve cells for the columns
            a = [g.getCells()[x][y] for x in range(self.n)]
            # get water levels for all the cells in the column
            water_levels = [x.water for x in a]
            # loop over the cells and check if any is not flooded
            for level in water_levels:
                if level < 0:
                    # if any of the cells is not flooded, percolation doesn't␣
↪occur and water is not flowing
```

```
                    flow = False
            if flow == True:
                # if flow is true i.e. all cells are flooded, set percolation to be True
                percolation = True
        # return the percolation variable
        return percolation


    def update(self):
        '''
        Method to update the entire system
        '''
        flow = 0

        #update all cells on their own first i.e. check to see if rain happened
        for x in range(self.n):
            for y in range(self.n):
                self.cells[x][y].update(self.prob)

        # update top row
        for y in range(self.n):
            x = 0
            current = self.cells[x][y]
            # make an empty array for neighbors
            neighbors = []
            # using a Von-Neuman neighborhood but not periodic conditions. Boundaries on the vertical axes are cut off.
            for dx, dy in [(1, 0), (0, -1), (0, 1)]:
                # append all the neighbors into the array
                neighbors.append(self.cells[dx][(y+dy)%self.n])
            # get height of the cell under consideration
            current_height = current.net_height
            # set steepest neighbor to be None by default in case our cell is in a valley
            steepest_neighbor = None
            # loop through the neighbors
            for n in neighbors:
                # if the neighbor is lower than current cell
                if n.net_height < current_height:
                    # if the steepest neighbor is None, set it to current neighbor
                    if steepest_neighbor == None:
                        steepest_neighbor = n
                        flow += 1
                    # if there is already a neighbor, compare the heights and choose the one with steepest decline
```

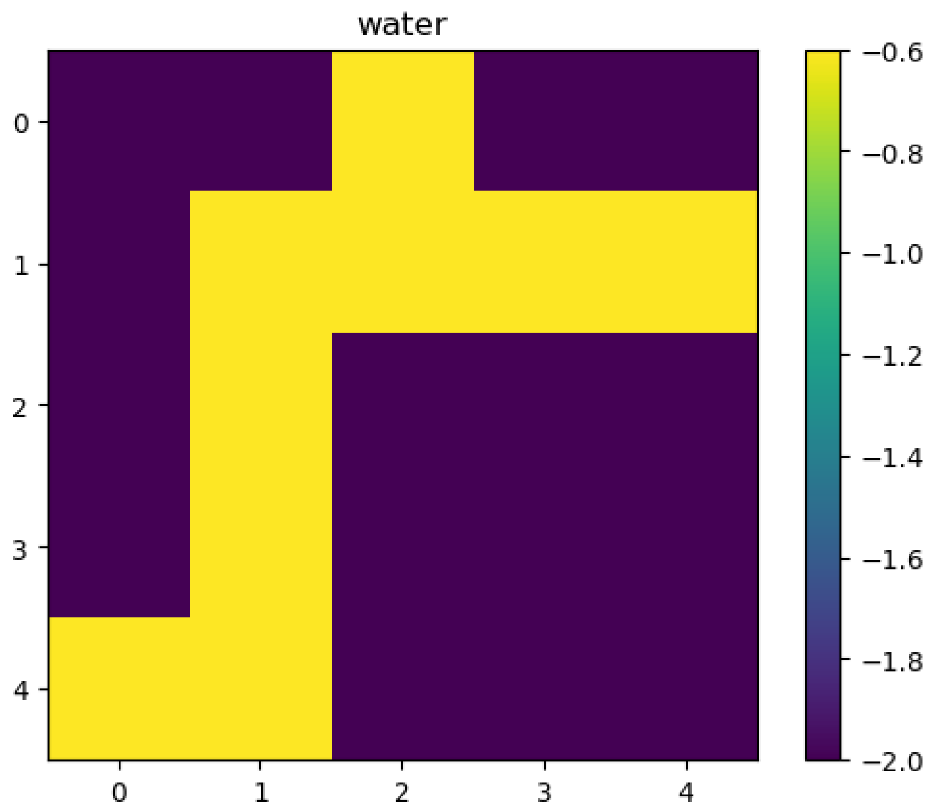
```
                else:
                    if n.net_height < steepest_neighbor.net_height:
                        steepest_neighbor = n

        #water flows to steepest neighbor
        if current.overflow > 0 and steepest_neighbor != None:
            # if the neighbor has a barrage, the water will be stopped by␣
↪it and absorbed into the surrounding soil
            if steepest_neighbor.barrage == 1:
                steepest_neighbor.water += 0
            else:
                # if the steepest neighbor has a water body near it, most␣
↪of the water drains into the water body
                # rather than to the city. Only 30% of the overflow makes␣
↪it to the neighboring cell
                if steepest_neighbor.water_body == 1:
                    steepest_neighbor.water += current.overflow * 0.3
                else:
                    steepest_neighbor.water += current.overflow
            # once water has flown to the neighbor, current overflow␣
↪becomes 0
            current.overflow = 0
            # update the neighbor based on water flow
            # neighbor becomes water logged if overflow caused its water␣
↪level to come level with the ground
            if steepest_neighbor.water == 0:
                steepest_neighbor.soil = 1
            # if water level is above the ground level
            elif steepest_neighbor.water > 0:
                # set the overflow value
                steepest_neighbor.overflow += steepest_neighbor.water
                steepest_neighbor.water = 0
                # set neighbor to be flooded
                steepest_neighbor.flooded = True
                # eighbor's soil becomes water logged
                steepest_neighbor.soil = 1
                # update neighbor's height
                steepest_neighbor.net_height = steepest_neighbor.altitude +␣
↪steepest_neighbor.water + steepest_neighbor.overflow

    # update all except boundaries
    for x in range(1, self.n-1):
        for y in range(self.n):
            current = self.cells[x][y]
            neighbors = []
            for dx, dy in [(-1, 0), (1, 0), (0, -1), (0, 1)]:
```

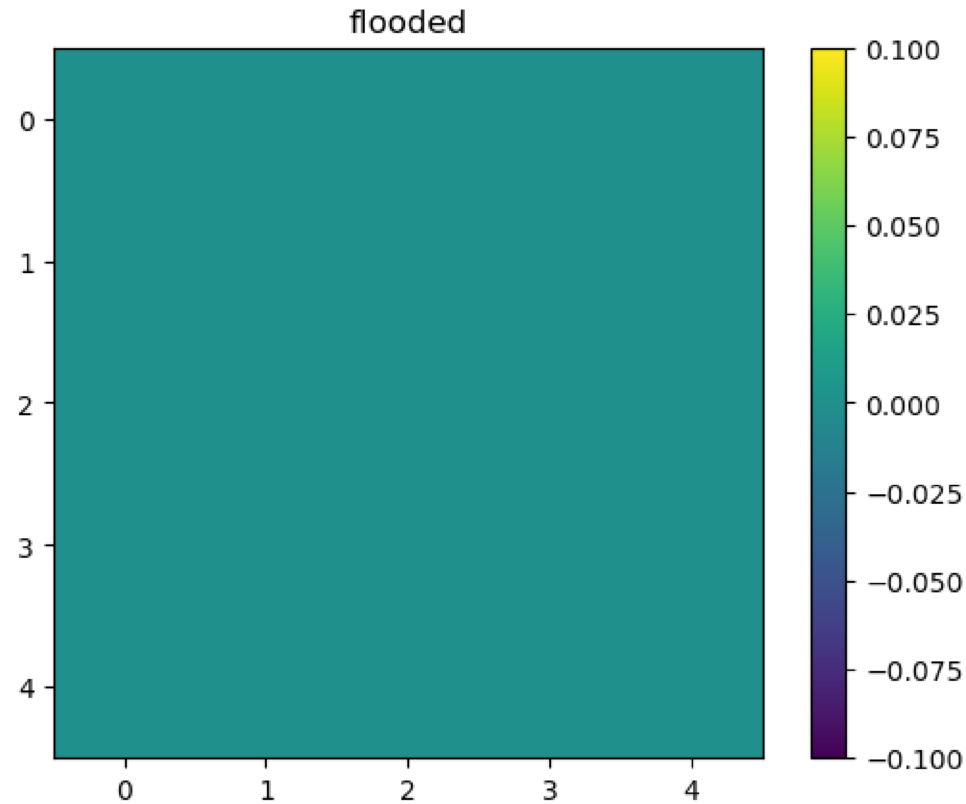
```
                    neighbors.append(self.cells[(x+dx)%self.n][(y+dy)%self.n])
                # find steepest neighbor
                current_height = current.net_height
                steepest_neighbor = None
                for n in neighbors:
                    if n.net_height < current_height:
                        # steep comparison
                        if steepest_neighbor == None:
                            steepest_neighbor = n
                            flow += 1
                        else:
                            if n.net_height < steepest_neighbor.net_height:
                                steepest_neighbor = n

                #water flows to steepest neighbor
                if current.overflow > 0 and steepest_neighbor != None:
                    # if the neighbor has a barrage, the water will be stopped␣
↪by it and absorbed into the surrounding soil
                    if steepest_neighbor.barrage == 1:
                        steepest_neighbor.water += 0
                    else:
                        # if the steepest neighbor has a water body near it,␣
↪most of the water drains into the water body
                        # rather than to the city. Only 30% of the overflow␣
↪makes it to the neighboring cell
                        if steepest_neighbor.water_body == 1:
                            steepest_neighbor.water += current.overflow * 0.3
                        else:
                            steepest_neighbor.water += current.overflow
                    current.overflow = 0
                    if steepest_neighbor.water == 0:
                        steepest_neighbor.soil = 1
                    elif steepest_neighbor.water > 0:
                        steepest_neighbor.overflow += steepest_neighbor.water
                        steepest_neighbor.water = 0
                        steepest_neighbor.flooded = True
                        steepest_neighbor.soil = 1
                        steepest_neighbor.net_height = steepest_neighbor.
↪altitude + steepest_neighbor.water + steepest_neighbor.overflow


        # update bottom row
        for y in range(self.n):
            x = 4
            neighbors = []
            current = self.cells[x][y]
            for dx, dy in [(-1, 0), (0, -1), (0, 1)]:
```

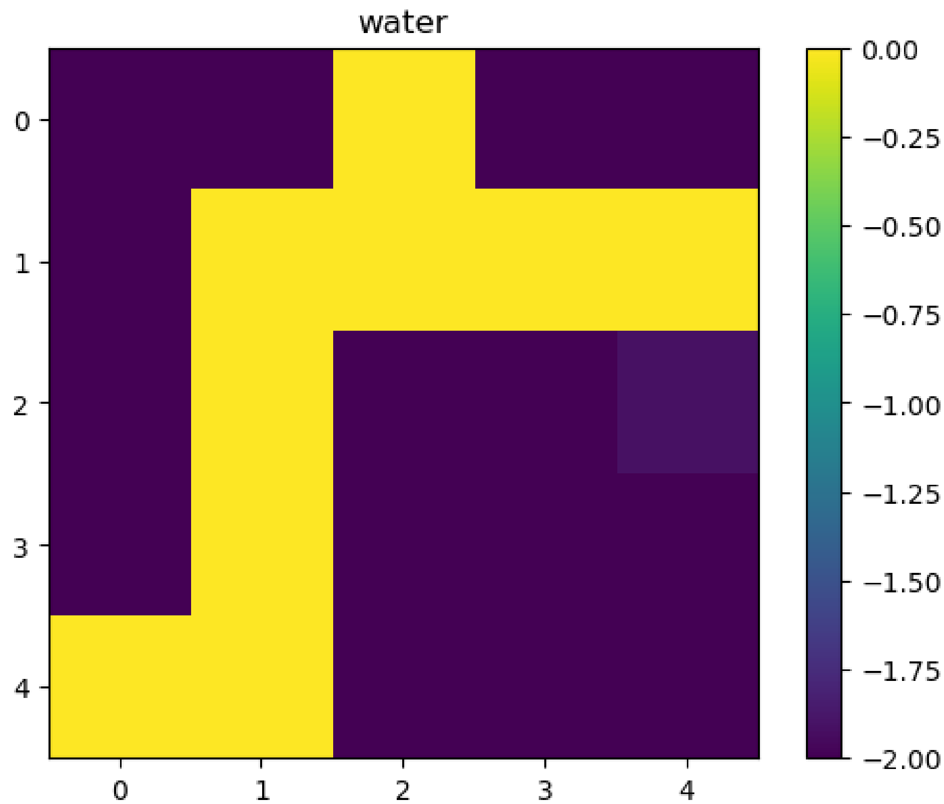
```
                neighbors.append(self.cells[(x+dx)%self.n][(y+dy)%self.n])
            # find steepest neighbor
            current_height = current.net_height
            steepest_neighbor = None
            for n in neighbors:
                if n.net_height < current_height:
                    # steep comparison
                    if steepest_neighbor == None:
                        steepest_neighbor = n
                        flow += 1
                    else:
                        if n.net_height < steepest_neighbor.net_height:
                            steepest_neighbor = n

            #water flows to steepest neighbor
            if current.overflow > 0 and steepest_neighbor != None:
                # if the neighbor has a barrage, the water will be stopped by␣
↪it and absorbed into the surrounding soil
                if steepest_neighbor.barrage == 1:
                    steepest_neighbor.water += 0
                else:
                    # if the steepest neighbor has a water body near it, most␣
↪of the water drains into the water body
                    # rather than to the city. Only 30% of the overflow makes␣
↪it to the neighboring cell
                    if steepest_neighbor.water_body == 1:
                        steepest_neighbor.water += current.overflow * 0.3
                    else:
                        steepest_neighbor.water += current.overflow
                current.overflow = 0
                if steepest_neighbor.water == 0:
                    steepest_neighbor.soil = 1
                elif steepest_neighbor.water > 0:
                    steepest_neighbor.overflow += steepest_neighbor.water
                    steepest_neighbor.water = 0
                    steepest_neighbor.flooded = True
                    steepest_neighbor.soil = 1
                    steepest_neighbor.net_height = steepest_neighbor.altitude +␣
↪steepest_neighbor.water + steepest_neighbor.overflow

        self.flow.append(flow/(self.n * self.n))
```

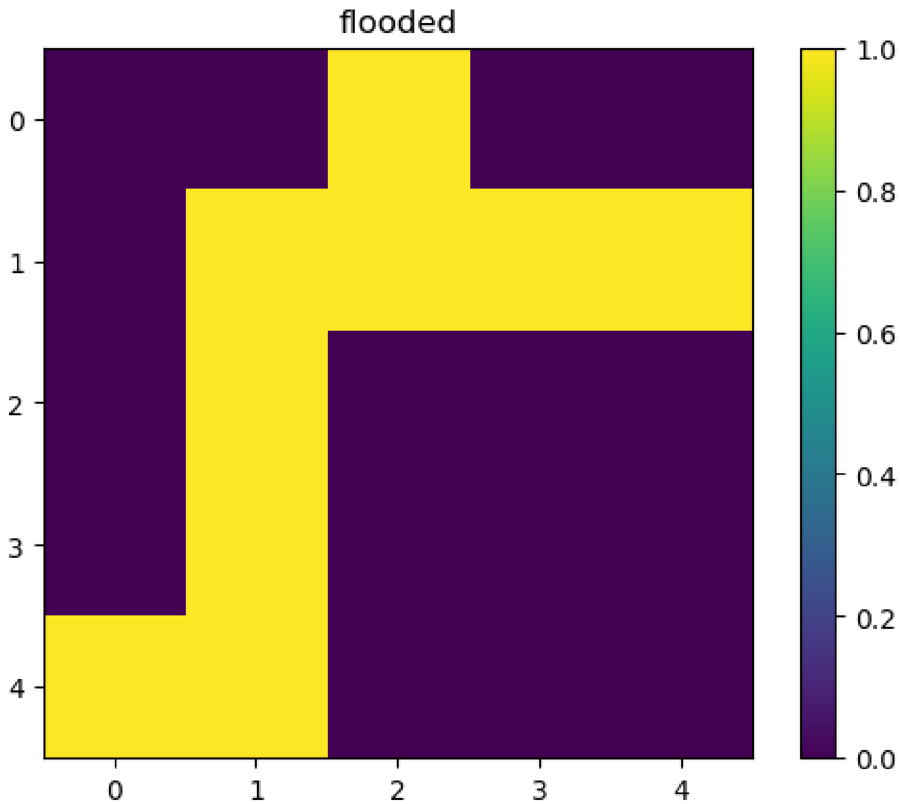
[5]:
```
# make an instance of the Grid
g = Grid()
# observe initial conditions of water levels and flooding
g.observe('water')
g.observe('flooded')
```

```python
# update for 60 days i.e. length of the moonsoon season
for i in range(60):
    g.update()
# observe final conditions
g.observe('water')
g.observe('flooded')
# check whether percolation occurs or not
print(g.percolation_test())
```




flooded
0
1
2
3
4
0
1
2
3
4
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100


water
0
1
2
3
4
0
1
2
3
4
0.00
−0.25
−0.50
−0.75
−1.00
−1.25
−1.50
−1.75
−2.00

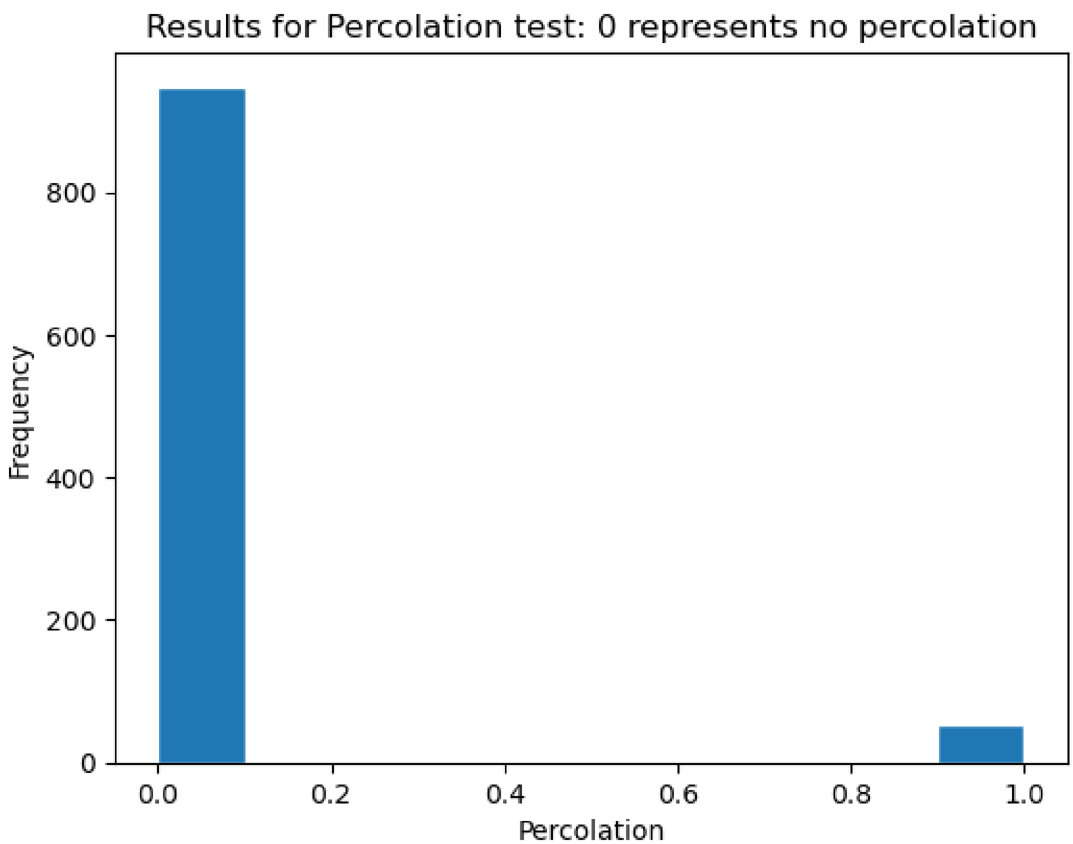



```
False
```

[6]:
```
for i in range(100):
    g = Grid()
    for j in range(365):
        g.update()
    if g.percolation_test == True:
        g.observe('flooded')
```

[7]:
```
#empirical runs
results_old = []
for i in range(1000):
    g = Grid()
    for j in range(60):
        g.update()
    if g.percolation_test() == False:
        results_old.append(0)
    else:
        results_old.append(1)
```

[8]:
```
plt.figure()
plt.title('Results for Percolation test: 0 represents no percolation')
plt.hist(results_old, edgecolor = 'white')
plt.xlabel('Percolation')
plt.ylabel('Frequency')
plt.show()
```



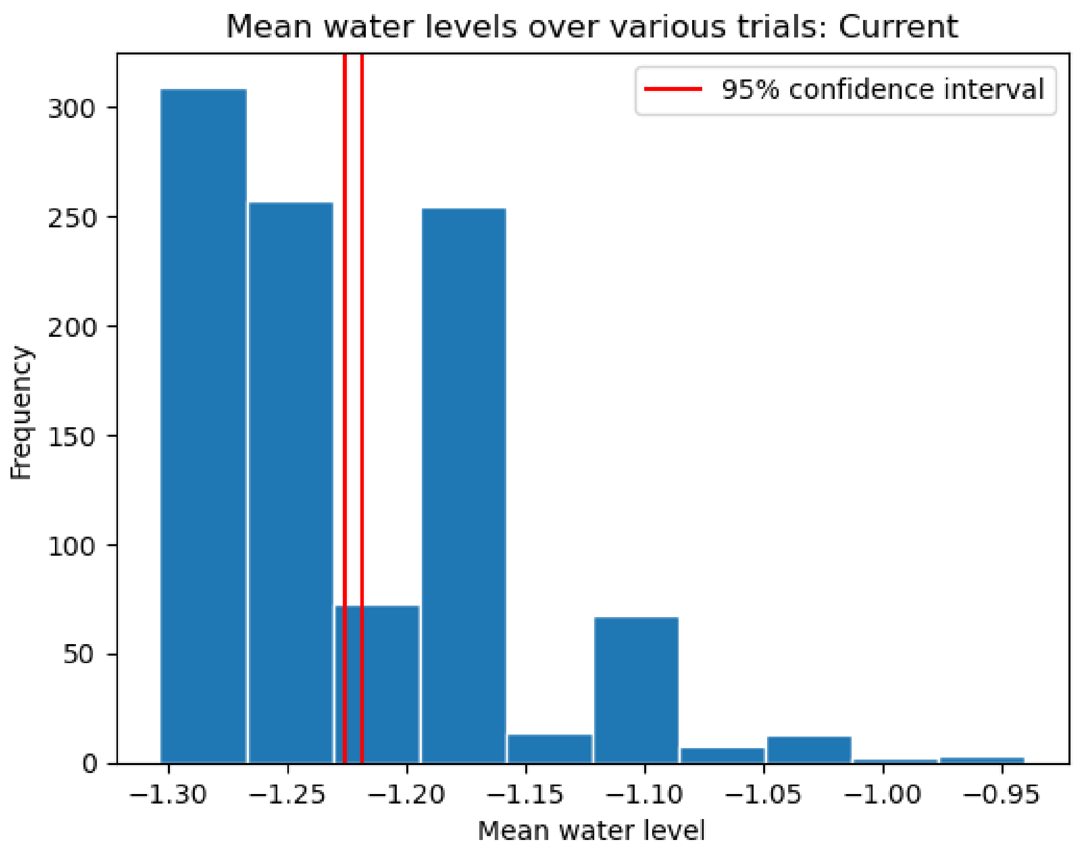
[9]:
```
# check for mean water levels in the grid at the end of the moonsoon season
mean_water_old = []
for i in range(1000):
    g = Grid()
    for j in range(60):
        g.update()
    water_levels = np.array(g.retrieve('water')).flatten()
    mean_water_old.append(np.mean(water_levels))
```

[10]:
```
def confint(lst):
    '''
    Function for calculating confidence intervals of a given list
```

```
    Inputs
    ------
        lst: list
            list of the data
    Outputs
    -------
        confint: list
            list of two values of confidence intervals.
    '''
    mean = np.mean(lst)
    standard_error = sts.sem(lst)
    deviation = standard_error * 1.96
    return [mean - deviation, mean + deviation]

confint_old = confint(mean_water_old)
```

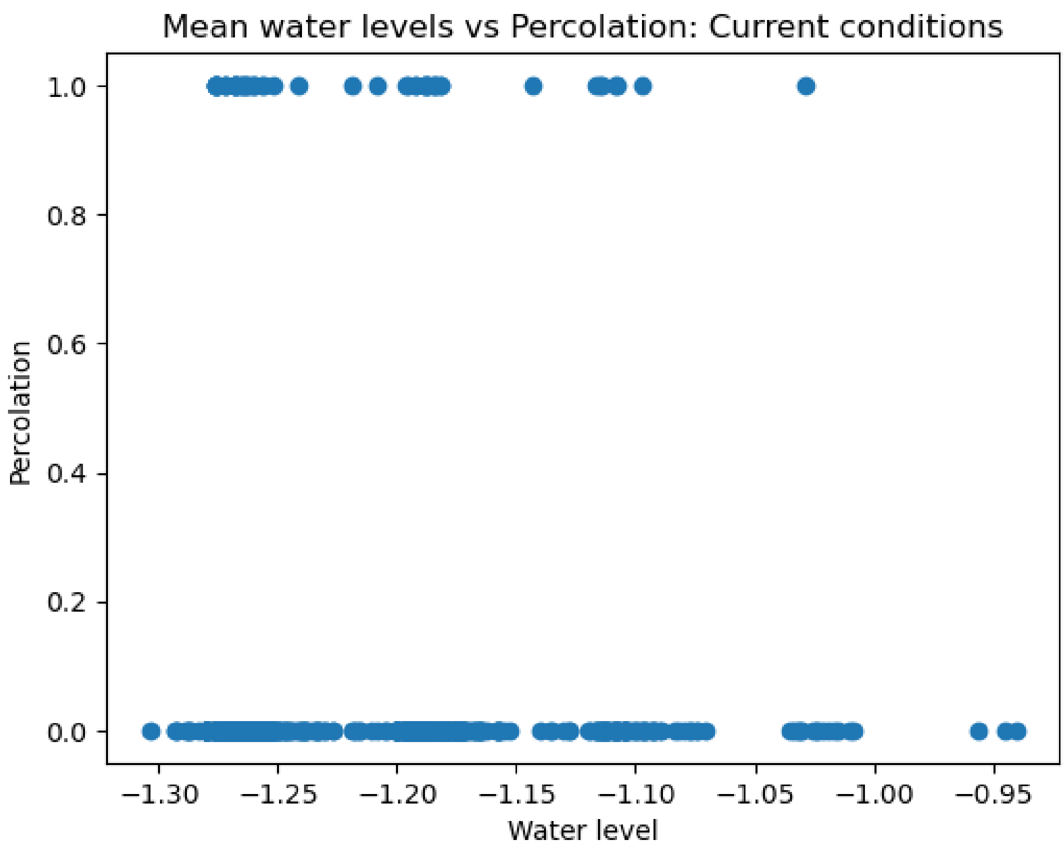
[11]:

```
plt.figure()
plt.title('Mean water levels over various trials: Current')
plt.hist(mean_water_old, edgecolor = 'white', bins = 10)
plt.axvline(confint_old[0], label = '95% confidence interval', color = 'red')
plt.axvline(confint_old[1], color = 'red')
plt.legend()
plt.xlabel('Mean water level')
plt.ylabel('Frequency')
plt.show()
print('95% Confidence interval: ', confint_old)
```




```
95% Confidence interval:  [-1.2258314132398211, -1.218445097265094]
```

[12]:
```
plt.figure()
plt.scatter(mean_water_old, results_old)
plt.title('Mean water levels vs Percolation: Current conditions')
plt.xlabel('Water level')
plt.ylabel('Percolation')
plt.show()
```



0.1 New conditions

[13]:
```
# run a small number of trials to see where the problem is
for i in range(5):
    g = Grid()
    for j in range(60):
        g.update()
    if g.percolation_test() == True:
        g.observe('flooded')
```

[14]:
```
# add barrages
barrage = [0]*10 + [1,1,1,0,0]*3

data = pd.DataFrame({
    'Names': names,
    'Altitude in meters': altitudes,
    'Annual Precipitation in meters': precipitation,
    'Rainy days as %age': percentage_days,
    'Average Rainfall in meters': height_per_rain,
    'Soil': soil,
```

```
    'Flooded': flooded,
    'Water Body present?': water_body,
    'Barrage': barrage
})
data
```

[14]:

	Names	Altitude in meters	Annual Precipitation in meters	\
0	Swat	980	0.67	
1	Skardu	2228	0.67	
2	Kohistan	1650	0.67	
3	Gilgit	1500	0.67	
4	Muzaffarabad	737	0.67	
5	Swabi	340	0.65	
6	Mianwali	210	0.65	
7	Gujrat	1110	0.65	
8	Nowshera	552	0.65	
9	Jhelum	234	0.65	
10	TTK	149	0.33	
11	Chiniot	179	0.33	
12	Lahore	217	0.33	
13	Bhakkar	159	0.33	
14	Jhang	158	0.33	
15	Lodhran	106	0.22	
16	Muzaffargarh	123	0.22	
17	Multan	122	0.22	
18	DGK	390	0.22	
19	Bahawalpur	118	0.22	
20	Karachi	10	0.29	
21	Sukkur	67	0.29	
22	Larkana	147	0.29	
23	Nawabshah	34	0.29	
24	Kashmore	66	0.29	

	Rainy days as %age	Average Rainfall in meters	Soil	Flooded	\
0	50	0.022333	0	False	
1	50	0.022333	0	False	
2	45	0.024815	1	False	
3	50	0.022333	0	False	
4	45	0.024815	0	False	
5	30	0.036111	0	False	
6	30	0.036111	1	False	
7	30	0.036111	1	False	
8	30	0.036111	1	False	
9	30	0.036111	1	False	
10	20	0.027500	0	False	
11	20	0.027500	1	False	
12	20	0.027500	0	False	

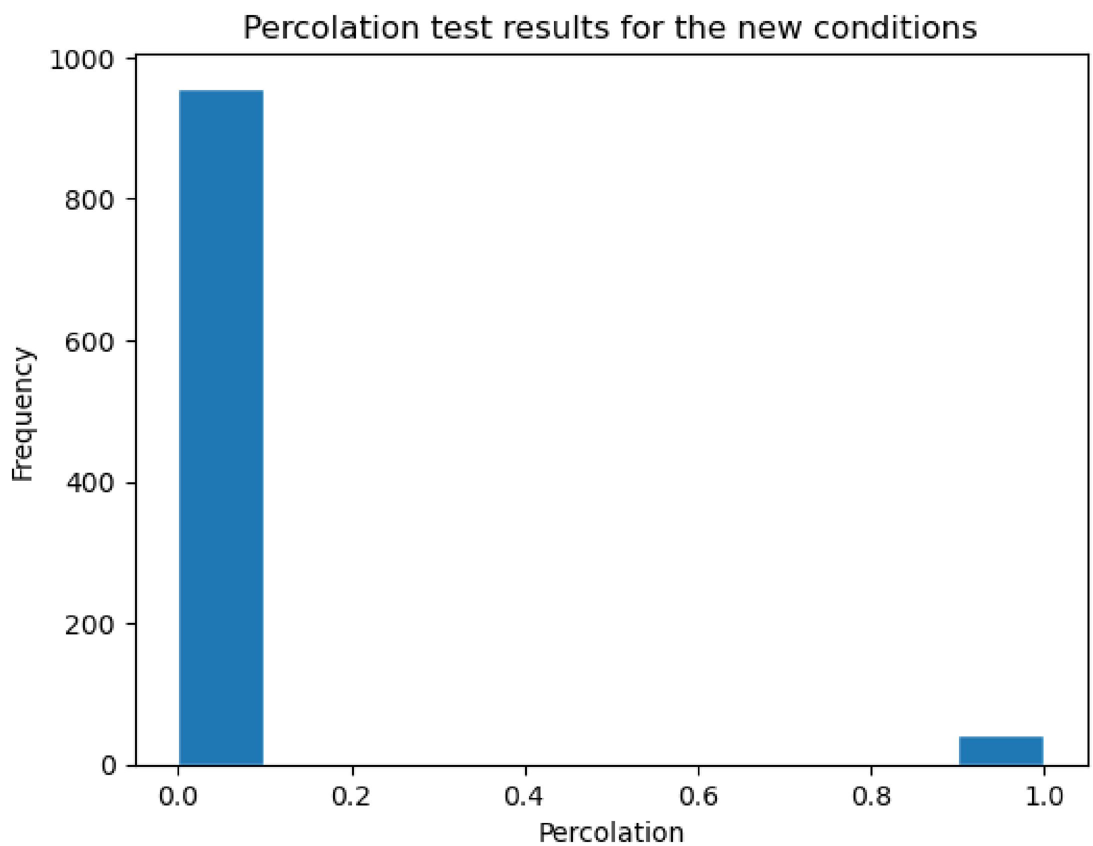
```
13                   20                    0.027500     0    False
14                   20                    0.027500     0    False
15                   10                    0.036667     0    False
16                   10                    0.036667     1    False
17                   10                    0.036667     0    False
18                   10                    0.036667     0    False
19                   10                    0.036667     0    False
20                   15                    0.032222     1    False
21                   15                    0.032222     1    False
22                   15                    0.032222     0    False
23                   15                    0.032222     0    False
24                   15                    0.032222     0    False

    Water Body present?  Barrage
0                     0        0
1                     0        0
2                     0        0
3                     0        0
4                     0        0
5                     1        0
6                     1        0
7                     1        0
8                     1        0
9                     1        0
10                    1        1
11                    1        1
12                    1        1
13                    1        0
14                    1        0
15                    1        1
16                    1        1
17                    1        1
18                    1        0
19                    1        0
20                    1        1
21                    1        1
22                    1        1
23                    0        0
24                    0        0
```

[15]:

```
#empirical runs
results_new = []
for i in range(1000):
    g = Grid()
    for j in range(60):
        g.update()
    if g.percolation_test() == False:
```

```
        results_new.append(0)
    else:
        results_new.append(1)
```

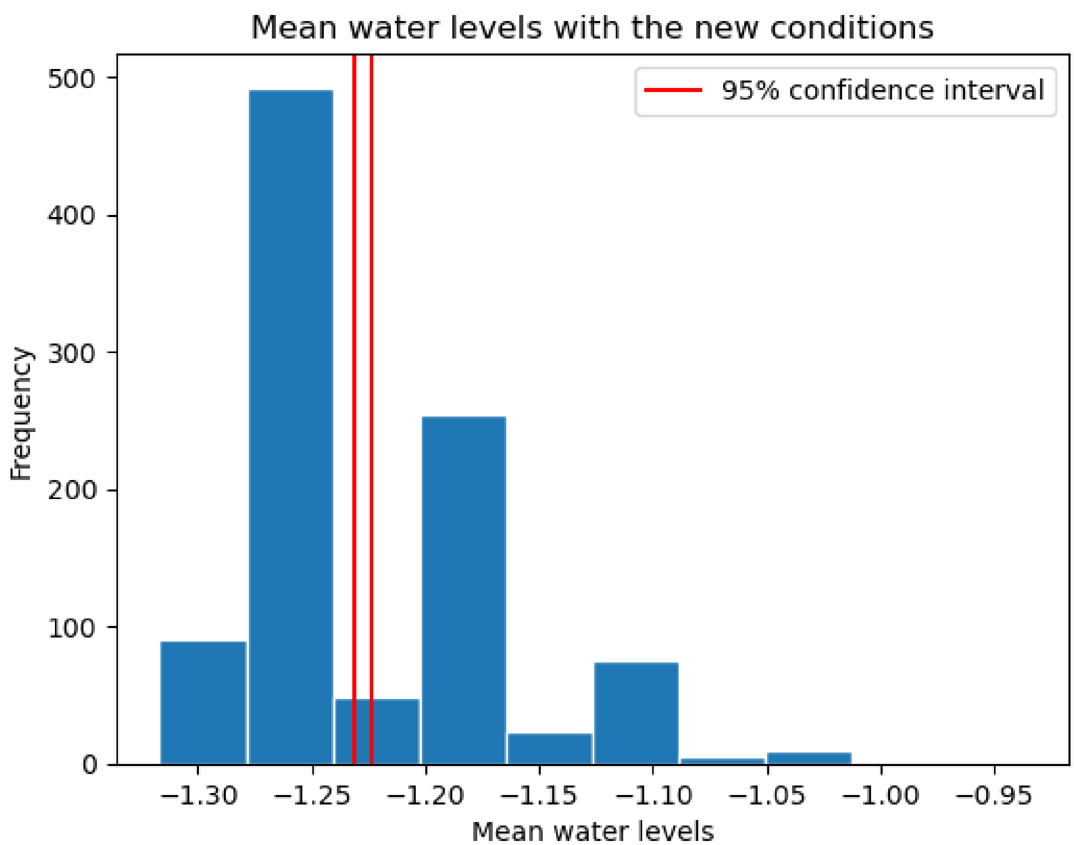
[16]:
```
plt.figure()
plt.title('Percolation test results for the new conditions')
plt.hist(results_new, edgecolor = 'white')
plt.xlabel('Percolation')
plt.ylabel('Frequency')
plt.show()
```



[17]:
```
mean_water_new = []
for i in range(1000):
    g = Grid()
    for j in range(60):
        g.update()
    water_levels = np.array(g.retrieve('water')).flatten()
    mean_water_new.append(np.mean(water_levels))
```

[18]:
```
confint_new = confint(mean_water_new)
```

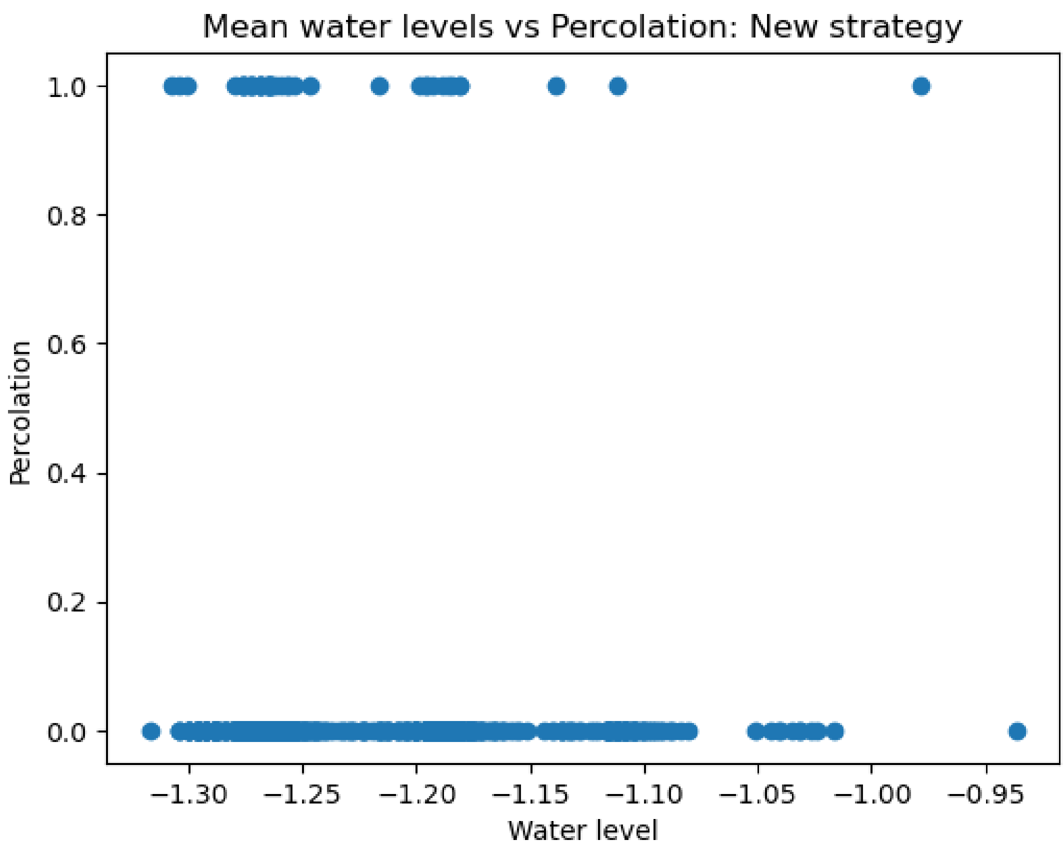
[19]:
```
plt.figure()
plt.title('Mean water levels with the new conditions')
plt.hist(mean_water_new, edgecolor = 'white', bins = 10)
plt.axvline(confint_new[0], label = '95% confidence interval', color = 'red')
plt.axvline(confint_new[1], color = 'red')
plt.legend()
plt.xlabel('Mean water levels')
plt.ylabel('Frequency')
plt.show()
print('95% confidence interval: ', confint_new)
```




```
95% confidence interval:  [-1.2307397064454368, -1.223509851716117]
```

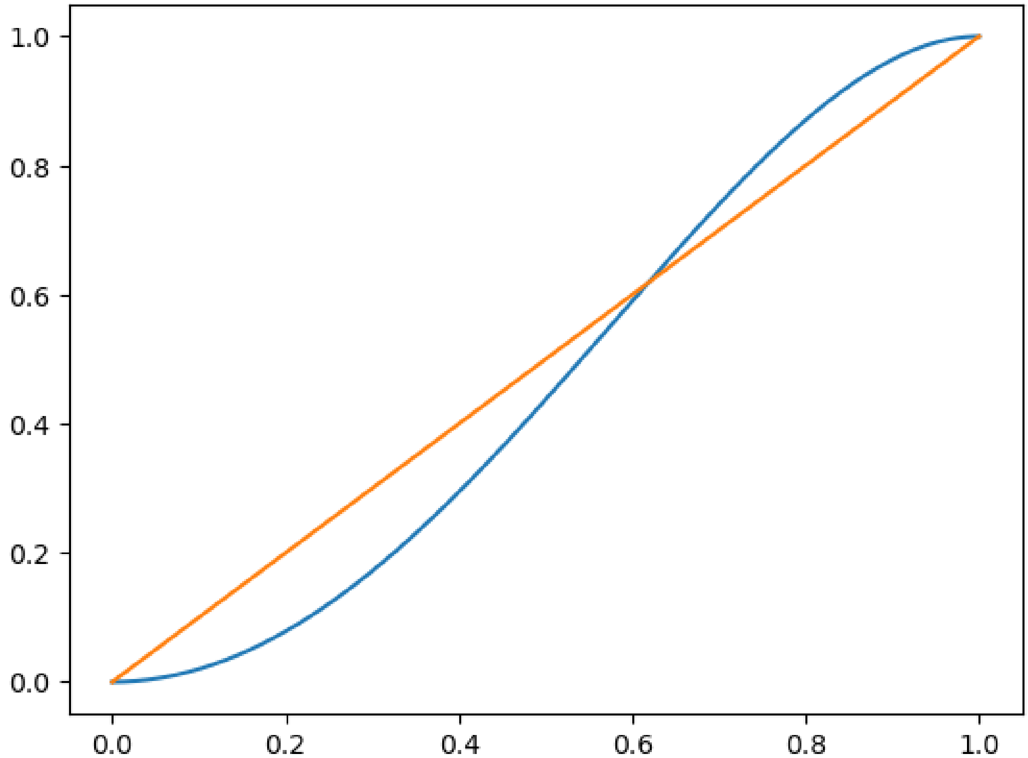
[20]:
```
for i in range(5):
    g = Grid()
    for j in range(60):
        g.update()
    if g.percolation_test() == True:
        g.observe('flooded')
```

[21]:
```
plt.figure()
plt.scatter(mean_water_new, results_new)
plt.title('Mean water levels vs Percolation: New strategy')
plt.xlabel('Water level')
plt.ylabel('Percolation')
plt.show()
```



0.1.1 Cobweb plot

[22]:
```
def f(x):
    return (x**4) + 4*(x**3)*(1-x) + 2*(x**2)*(1-x)**2

x = np.linspace(0,1,1000)
plot = [f(value) for value in x]
diagonal = [value for value in x]
plt.figure()
plt.plot(x, plot)
plt.plot(x, diagonal)
plt.show()
```



0.1.2 Average probability of having a lower altitude neighbor in our model

[23]:
```
g = Grid()
for i in range(60):
    g.update()
np.mean(g.flow)
```

[23]: 0.8800000000000002