

## Requirements

Implement a solution for the problem of crude oil pipeline operation:

1. Create a population of 16 stations for petrol extraction, with 16 tanks, and 16 pumps
2. Initial levels of the tank is 40 percent of their storage capacity, with variance standard deviation of 10. Input per tank is 10 gallon/hour with standard deviation of 3. The pipeline total capacity is to dispatch 200 gallons per hour with all pumps turned on, each pump can on average dispatch 12 gallons per hour with a random standard deviation of 2 gallons.
3. Define a rule or strategy to optimize the pipeline optimization and the best time scale for simulation; try stabilized the system, with the volume of storage tank around 50 percent; simulate a dynamic 48 hours scenario. Create a solution that will reach following goals: (a) try to keep the tank levels closest to 50 percent; (b) maximize the lifespan of the pipeline; (c) minimize the electricity consumption; (d) keep the delivery flow as close as possible to a constant flow at 160 gallons per hour;

## Solution

The code consists of two parts, the simulation and optimization using Metropolis Markov chain Monte Carlo. Each simulation happens in a 48 hours duration, every hour a step can be taken to change the pump switch. To evaluate every simulation, a loss function value is calculated based upon the tank level mean error and standard deviation, total pump volume mean error and standard deviation and number of switch change. Then optimization can be done by applying Metropolis MCMC of generate a candidate  $x'$  value within the desired probability distribution then accept or reject it based on its acceptance ratio of  $f(x')/f(x)$ . From the result, 1 hour interval and turning on the pipe below 50.29 percent is preferred for this current station.

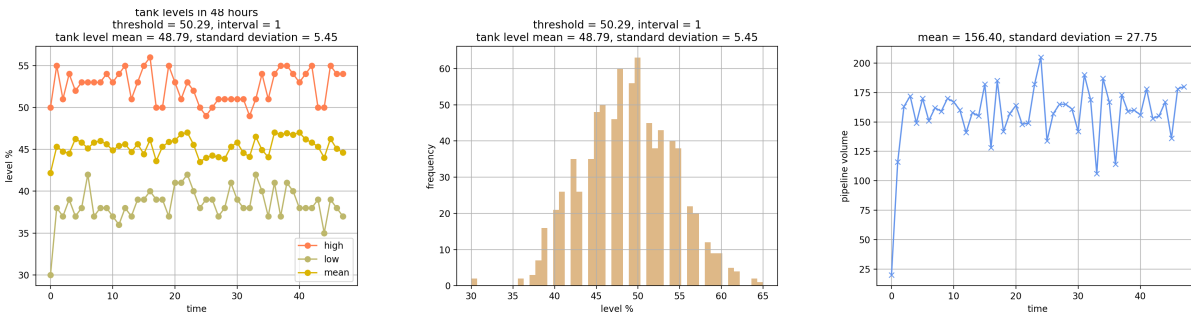


Figure 1: Simulation of 48 hours with 1 hour step interval

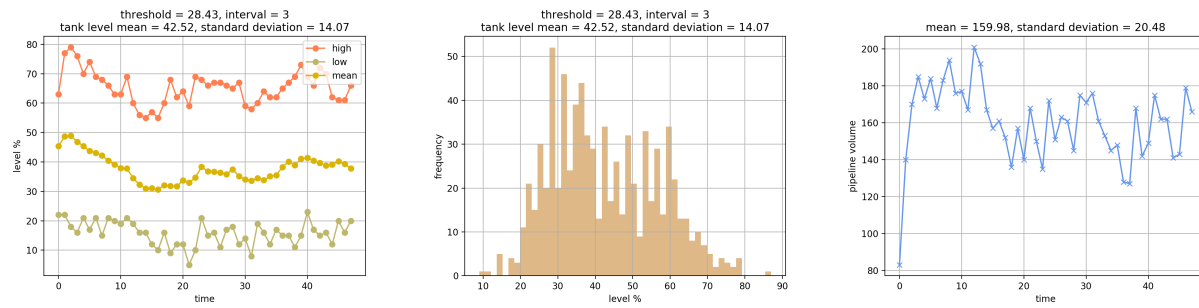


Figure 2: Simulation of 48 hours with 3 hour step interval

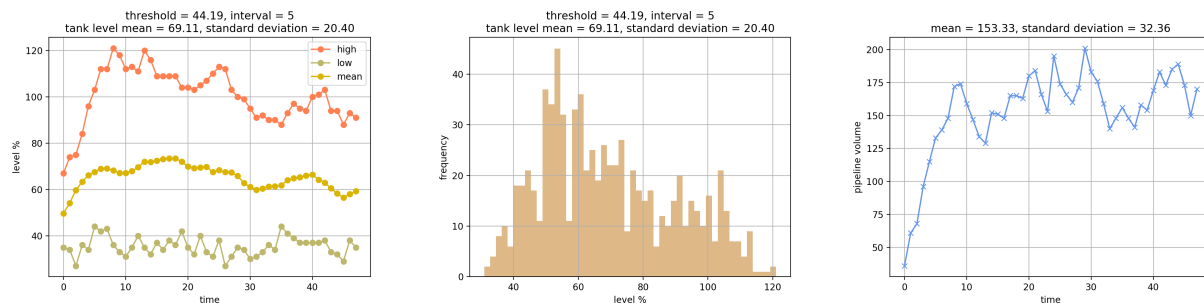


Figure 3: Simulation of 48 hours with 5 hour step interval

hour	0															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	19.0	28.0	40.0	49.0	41.0	36.0	26.0	37.0	30.0	28.0	44.0	31.0	30.0	35.0	35.0	28.0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hour	1															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	30.0	36.0	48.0	42.0	47.0	48.0	39.0	46.0	44.0	39.0	50.0	40.0	38.0	45.0	41.0	42.0
hour	2															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	0	1	1	1	1	1	1	0	0	1	1	0	1	0	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	48.0	44.0	46.0	40.0	46.0	46.0	38.0	45.0	50.0	50.0	55.0	40.0	43.0	42.0	50.0	42.0
hour	3															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	49.0	37.0	39.0	39.0	43.0	48.0	50.0	47.0	49.0	42.0	49.0	39.0	51.0	39.0	47.0	48.0
hour	4															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	52.0	46.0	47.0	41.0	42.0	48.0	48.0	40.0	48.0	41.0	41.0	39.0	54.0	42.0	41.0	42.0
hour	5															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	48.0	46.0	45.0	37.0	50.0	50.0	49.0	49.0	50.0	49.0	41.0	42.0	52.0	49.0	41.0	42.0
hour	6															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	52.0	48.0	47.0	46.0	43.0	46.0	46.0	45.0	48.0	45.0	38.0	43.0	53.0	44.0	50.0	39.0
hour	7															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	45.0	46.0	45.0	44.0	42.0	44.0	44.0	42.0	48.0	42.0	45.0	50.0	44.0	44.0	53.0	44.0
hour	8															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	49.0	49.0	48.0	44.0	40.0	38.0	44.0	50.0	50.0	37.0	43.0	48.0	50.0	50.0	53.0	40.0
hour	9															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	47.0	43.0	47.0	41.0	47.0	38.0	46.0	53.0	48.0	50.0	46.0	44.0	47.0	48.0	52.0	39.0
hour	10															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	45.0	41.0	45.0	42.0	38.0	47.0	44.0	54.0	43.0	47.0	45.0	47.0	47.0	50.0	54.0	41.0

hour	11															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	40.0	40.0	47.0	41.0	48.0	47.0	50.0	53.0	42.0	45.0	37.0	45.0	41.0	51.0	52.0	39.0
hour	12															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	45.0	48.0	45.0	50.0	49.0	45.0	50.0	49.0	36.0	41.0	43.0	40.0	42.0	52.0	54.0	38.0
hour	13															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	0	0	0	1	0	1	1	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	40.0	42.0	41.0	49.0	43.0	47.0	48.0	49.0	40.0	50.0	48.0	38.0	49.0	46.0	55.0	45.0
hour	14															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	48.0	42.0	37.0	49.0	40.0	39.0	45.0	51.0	48.0	41.0	44.0	47.0	47.0	43.0	49.0	45.0
hour	15															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	42.0	49.0	49.0	46.0	43.0	47.0	42.0	53.0	48.0	39.0	42.0	50.0	46.0	41.0	51.0	42.0
hour	16															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	40.0	48.0	41.0	47.0	42.0	44.0	50.0	52.0	42.0	41.0	43.0	55.0	45.0	39.0	41.0	41.0
hour	17															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	42.0	41.0	49.0	49.0	40.0	46.0	48.0	56.0	43.0	47.0	40.0	48.0	44.0	46.0	49.0	50.0
hour	18															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	41.0	41.0	42.0	44.0	39.0	42.0	43.0	49.0	50.0	46.0	41.0	42.0	41.0	45.0	45.0	47.0
hour	19															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	0	0	1	1	1	1	1	0	1	0	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	44.0	42.0	40.0	50.0	48.0	39.0	47.0	50.0	45.0	41.0	50.0	40.0	47.0	50.0	48.0	44.0
hour	20															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	0	1	1	0	1	1	1	1	1	0	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	42.0	43.0	49.0	49.0	45.0	48.0	47.0	48.0	41.0	37.0	47.0	48.0	46.0	55.0	47.0	42.0
hour	21															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	49.0	41.0	47.0	47.0	46.0	47.0	50.0	46.0	42.0	46.0	44.0	47.0	47.0	53.0	41.0	44.0

hour	22															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	0	1	1	1	1	1	1	1	1	0	1	1	1	0	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	44.0	48.0	50.0	44.0	50.0	41.0	47.0	46.0	51.0	48.0	50.0	47.0	41.0	48.0	46.0	48.0
hour	23															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	42.0	49.0	48.0	50.0	53.0	50.0	42.0	44.0	50.0	51.0	46.0	46.0	49.0	43.0	45.0	44.0
hour	24															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	42.0	52.0	44.0	50.0	50.0	43.0	49.0	40.0	48.0	44.0	42.0	45.0	49.0	43.0	48.0	40.0
hour	25															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	44.0	47.0	45.0	43.0	47.0	42.0	44.0	38.0	42.0	41.0	39.0	50.0	46.0	42.0	45.0	41.0
hour	26															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	43.0	48.0	42.0	39.0	43.0	40.0	42.0	44.0	46.0	47.0	45.0	49.0	45.0	40.0	42.0	49.0
hour	27															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	48.0	46.0	39.0	39.0	41.0	46.0	41.0	45.0	44.0	48.0	40.0	45.0	50.0	48.0	45.0	43.0
hour	28															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	44.0	43.0	41.0	48.0	45.0	40.0	50.0	43.0	40.0	45.0	37.0	44.0	51.0	51.0	37.0	46.0
hour	29															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	42.0	43.0	40.0	46.0	46.0	38.0	51.0	43.0	38.0	49.0	48.0	38.0	46.0	51.0	42.0	41.0
hour	30															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	50.0	44.0	46.0	43.0	43.0	50.0	51.0	46.0	47.0	42.0	45.0	43.0	41.0	48.0	43.0	43.0
hour	31															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	46.0	45.0	47.0	45.0	49.0	51.0	51.0	44.0	42.0	49.0	46.0	46.0	42.0	46.0	45.0	39.0
hour	32															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	42.0	45.0	41.0	47.0	51.0	46.0	49.0	43.0	40.0	46.0	45.0	49.0	41.0	38.0	48.0	42.0

hour	33															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	39.0	47.0	39.0	46.0	49.0	45.0	46.0	40.0	47.0	48.0	41.0	47.0	49.0	47.0	38.0	38.0
hour	34															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	1	0	1	1	0	1	0	1	1	0	1	1	1	0	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	46.0	44.0	49.0	42.0	44.0	49.0	51.0	45.0	47.0	49.0	50.0	43.0	43.0	50.0	46.0	46.0
hour	35															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	41.0	41.0	43.0	48.0	45.0	44.0	46.0	44.0	50.0	43.0	53.0	40.0	40.0	54.0	40.0	47.0
hour	36															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	46.0	40.0	50.0	45.0	41.0	43.0	39.0	42.0	51.0	49.0	51.0	37.0	41.0	51.0	40.0	39.0
hour	37															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	0	0	1	1	1	0	0	1	0	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	50.0	41.0	49.0	48.0	41.0	43.0	48.0	48.0	48.0	54.0	46.0	43.0	47.0	48.0	50.0	48.0
hour	38															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	52.0	37.0	46.0	50.0	39.0	49.0	40.0	51.0	51.0	55.0	44.0	47.0	44.0	50.0	51.0	42.0
hour	39															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	47.0	44.0	46.0	50.0	48.0	49.0	46.0	50.0	41.0	55.0	41.0	42.0	42.0	50.0	52.0	48.0
hour	40															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	41.0	42.0	41.0	50.0	49.0	54.0	45.0	46.0	40.0	49.0	45.0	49.0	50.0	49.0	49.0	49.0
hour	41															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	49.0	49.0	38.0	53.0	40.0	52.0	40.0	42.0	48.0	53.0	49.0	50.0	50.0	47.0	47.0	45.0
hour	42															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	46.0	47.0	48.0	52.0	40.0	51.0	42.0	47.0	54.0	50.0	47.0	46.0	38.0	38.0	47.0	46.0
hour	43															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	44.0	40.0	42.0	50.0	50.0	47.0	42.0	38.0	45.0	48.0	49.0	55.0	44.0	45.0	49.0	45.0

hour	44															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	44.0	43.0	50.0	48.0	50.0	40.0	39.0	46.0	46.0	44.0	50.0	49.0	43.0	45.0	45.0	43.0
hour	45															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	50.0	49.0	47.0	48.0	44.0	49.0	35.0	44.0	44.0	42.0	48.0	45.0	37.0	40.0	40.0	42.0
hour	46															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	0	1	1	0	1	1	0	0	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	49.0	52.0	44.0	55.0	39.0	45.0	45.0	45.0	42.0	50.0	49.0	49.0	45.0	48.0	42.0	41.0
hour	47															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	46.0	54.0	39.0	51.0	41.0	38.0	43.0	47.0	41.0	48.0	45.0	43.0	41.0	48.0	50.0	46.0
hour	48															
pump	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
volume	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1
tank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
level	40.0	52.0	40.0	45.0	37.0	48.0	40.0	45.0	50.0	54.0	40.0	40.0	40.0	48.0	49.0	46.0