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A Hierarchical Water Supply–Demand Regulation Model Coupling System Dynamics and Feedback Control Mechanisms: A Case Study in Wu'an City, China

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Supplementary Material for "A Hierarchical Water Supply–Demand Regulation Model Coupling System Dynamics and Feedback Control Mechanisms: A Case Study in Wu'an City, China"

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Table S1. The equations of the SD-F-HWD model (Low-flow year).

Table S2. Actual and predicted values of each typical variable for the validation period 2020-2022 in Wu'an.

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Table S1. The equations and parameters of the SD-F-HWD model(Low-flow year).The simulation period of the model is from time 1 to time 10, where time 1-8 represents the simulation process from 2023 to 2030. Time 9-10 represents the control group before and after the simulation results feedback control in 2030.

	Formulas	Note	Units
1	**water scarcity rate**=INTEG((total water demand-total water supply)/total water demand-water scarcity rate)	/	Dmnl
2	**β1.1**=STEP(0.7, 10)	/	Dmnl
3	**β1.2**=STEP(0.7, 10)	/	Dmnl
4	**β1.3**=STEP(0.7, 10)	/	Dmnl
5	**β1.4**=STEP(0.7, 10)	/	Dmnl
6	**β1.5**=STEP(0.7, 10)	/	Dmnl
7	**β1.6**=STEP(0.7, 10)	/	Dmnl
8	**β1.7**=STEP(0.7, 10)	/	Dmnl
9	**α1.1**=1-ARCTAN(1*water scarcity rate*β1.1)*1/ARCTAN(1)	/	Dmnl
10	**α1.2**=1-ARCTAN(1*water scarcity rate*β1.2)*1/ARCTAN(1)	/	Dmnl
11	**α1.3**=1-ARCTAN(1*water scarcity rate*β1.3)*1/ARCTAN(1)	/	Dmnl
12	**α1.4**=1-ARCTAN(1*water scarcity rate*β1.4)*1/ARCTAN(1)	/	Dmnl
13	**α1.5**=1+ARCTAN(1*water scarcity rate*β1.5)*1/ARCTAN(1)	/	Dmnl
14	**α1.6**=1-ARCTAN(1*water scarcity rate*β1.6)*1/ARCTAN(1)	/	Dmnl
15	**α1.7**=1-ARCTAN(1*water scarcity rate*β1.7)*1/ARCTAN(1)	/	Dmnl
16	**urbanisation rate** = WITH LOOK UP(Time, ([(0,0)-(10,10)],(1,0.602583),(2,0.615874),(3,0.628525),(4,0.640532),(5,0.651897),(6,0.662625),(7,0.672728),(8,0.682219),(9,0.682219),(10,0.682219)))	/	Dmnl
17	**volume of change in population growth** = ACTIVE INITIAL(IF THEN ELSE(Time<=8, ((1+"#population growth rate")^(Time)-1)*81.7439, ((1+"#population growth rate")^(8)-1)*81.7439))	The value 81.7439 represents the population count in 2022.	10^4 persons
18	**total population** = volume of change in population growth+81.7439	/	10^4 persons
19	**urban population** = urbanisation rate*total population	/	10^4 persons
20	**rural population** = total population-urban population	/	10^4 persons
21	**population growth rate** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,0.00660053),(10,0.00660053)))	/	Dmnl
22	#**population growth rate** = IF THEN ELSE("α1.6"*population growth rate<=0 ,0, "α1.6"*population growth rate)	The value 0 represents the lower control limit for population growth rate.	Dmnl
23	**urban domestic water consumption quota** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,33.5),(10,33.5)))	/	m^3/(person·year)
24	#**urban domestic water consumption quota** = IF THEN ELSE("α1.1"*urban domestic water consumption quota<=30 , 30 ,"α1.1"*urban domestic water consumption quota)	The value 30 represents the lower control limit for urban domestic water consumption quota.	m^3/(person·year)
25	**rural domestic water consumption quota** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,22),(10,22)))	/	m^3/(person·year)
26	#**rural domestic water consumption quota** = IF THEN ELSE("α1.1"*rural domestic water consumption quota<=18.5 , 18.5 ,"α1.1"*rural domestic water consumption quota)	The value 18.5 represents the lower control limit for rural domestic water consumption quota.	m^3/(person·year)

	Formulas	Note	Units
27	**urban domestic water demand** = (urban population*"#urban domestic water consumption quota")/(1-0.05)	The value 0.05 represents the domestic water supply loss factor.	10^4m^3
28	**rural domestic water demand** = (rural population*"#rural domestic water consumption quota")/(1-0.05)	The value 0.05 represents the domestic water supply loss factor.	10^4m^3
29	**domestic water demand** = (rural domestic water demand+urban domestic water demand)	/	10^4m^3
30	**rural rigid domestic water consumption quota** = 18.5	/	m^3/(person·year)
31	**urban rigid domestic water consumption quota** = 30	/	m^3/(person·year)
32	**rural rigid domestic water demand** = (rural population*rural rigid domestic water consumption quota)/(1-0.05)	The value 0.05 represents the domestic water supply loss factor.	10^4m^3
33	**urban rigid domestic water demand** = (urban population*urban rigid domestic water consumption quota)/(1-0.05)	The value 0.05 represents the domestic water supply loss factor.	10^4m^3
34	**domestic rigid water demand** = (rural rigid domestic water demand+urban rigid domestic water demand)	/	10^4m^3
35	**volume of change in industrial value added** = IF THEN ELSE(Time<=8, ((1+"#industrial value added growth rate")^(Time)-1)*420.18, ((1+"#industrial value added growth rate")^(8)-1)*420.18)	The value 420.18 represents the industrial value added in 2022.	CNY 10^4
36	**industrial value added** = volume of change in industrial value added+420.18	/	CNY 10^4
37	**industrial value added growth rate** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,0.028678),(10,0.028678)))	/	Dmnl
38	**#industrial value added growth rate** = IF THEN ELSE("α1.7"*industrial value added growth rate<=0.0074, 0.0074 ,"α1.7"*industrial value added growth rate)	The value 0.0074 represents the lower control limit for industrial value added growth rate.	Dmnl
39	**water consumption per CNY 10^4 of industrial value added** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,21.6),(10,21.6)))	/	m^3/(CNY 10^4)
40	**#water consumption per CNY 10^4 of industrial value added** = IF THEN ELSE("α1.2"*water consumption per CNY 10^4 of industrial value added<=17.4 , 17.4 , "α1.2"*water consumption per CNY 10^4 of industrial value added)	The value 17.4 represents the lower control limit for water consumption per CNY 10^4 of industrial value added.	m^3/(CNY 10^4)
41	**industrial water demand** = ("#water consumption per CNY 10^4 of industrial value added"*industrial value added)/(1-0.05)	The value 0.05 represents the industrial water supply loss factor.	10^4m^3
42	**industrial value added growth rate in leading industries** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,0.0287),(10,0.0287)))	/	m^3/(CNY 10^4)
43	**volume of change in industrial value added of leading industries** = IF THEN ELSE(Time<=8, ((1+industrial value added growth rate in leading industries)^(Time)-1)*327.308, ((1+industrial value added growth rate in leading industries)^(8)-1)*327.308)	The value 327.308 represents the industrial value added of leading industries in 2022.	CNY 10^4
44	**industrial value added of leading industries** = me of change in industrial value added of leading industries+327.308	/	CNY 10^4
45	**industrial rigid water demand** = ("#water consumption per CNY 10^4 of industrial value added"*industrial value added of leading industries)/(1-0.05)	/	10^4m^3

	Formulas	Note	Units
46	**per capita green space area** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,15.211),(2,15.2221),(3,15.2332),(4,15.2442),(5,15.2553),(6,15.2664),(7,15.2775),(8,15.2886)))	/	m^2/person
47	**greening water quota** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,0.22),(10,0.22)))	/	m^3/(m^2·year)
48	#**greening water quota** = "α1.4"*greening water quota	/	m^3/(m^2·year)
49	**terrestrial ecological water demand** = per capita green space area*urban population*"#greening water quota"	/	10^4m^3
50	**ecological water demand** = terrestrial ecological water demand	/	10^4m^3
51	**rigid per capita green space area** = WITH LOOKUP(Time, ([(0,0)-(10,10)],(1,8),(10,8)))	/	m^2/person
52	**rigid terrestrial ecological water demand** = "#greening water quota"*rigid per capita green space area*urban population	/	10^4m^3
53	**ecological rigid water demand** = rigid terrestrial ecological water demand	/	10^4m^3
54	**actual area for irrigation of forestry** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,777.78),(10,777.78)))	/	ha
55	**actual irrigated area for grain crops** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,10400),(10,10400)))	/	ha
56	**comprehensive irrigation quota for grain crops** = ITH LOOKUP(Time,([(0,0)-(10,10)],(1,2229.76),(10,2229.76)))	/	m^3/ha
57	**comprehensive irrigation water quota for forestry** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,2593.71),(10,2593.71)))	/	m^3/ha
58	#**comprehensive irrigation quota for grain crops** = IF THEN ELSE("α1.3"*comprehensive irrigation quota for grain crops<=1873.46 , 1873.46 , "α1.3"*comprehensive irrigation quota for grain crops)	The value 1873.46 represents the lower control limit for omprehensive irrigation quota for grain crops.	m^3/ha
59	#**comprehensive irrigation water quota for forestry** = IF THEN ELSE("α1.3"*comprehensive irrigation water quota for forestry<=2265.18 , 2265.18 , "α1.3"*comprehensive irrigation water quota for forestry)	The value 2265.18 represents the lower control limit for comprehensive irrigation water quota for forestry.	m^3/ha
60	**water demand for irrigation of grain crops** = ("#comprehensive irrigation quota for grain crops"*actual irrigated area for grain crops/0.6)/10000	The value 0.6 represents the effective utilization coefficient of irrigation water.	10^4m^3
61	**water demand for irrigation of forestry** = ("#comprehensive irrigation water quota for forestry"*actual area for irrigation of forestry)/10000	/	10^4m^3
62	**agricultural water demand** = water demand for irrigation of grain crops+water demand for irrigation of forestry	/	10^4m^3
63	**grain self-sufficiency rate** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,0.9),(10,0.9)))	/	/
64	**per capita grain demand** = 400	/	kg/person
65	**total grain requirements** = per capita grain demand*total population*"grain self-sufficiency rate"*10000	/	kg
66	**grain yield per unit area of irrigated land** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,14326),(2,14411.1),(3,14496.8),(4,14582.9),(5,14669.6),(6,14756.8),(7,14844.5),(8,14932.7),(9,14932.7),(10,14932.7)))	/	kg/ha

	Formulas	Note	Units
67	**minimum sown area of irrigated land** = total grain requirements/grain yield per unit area of irrigated land	/	ha
68	**ratio of food to cash crop acreage** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,1.24732),(2,1.27202),(3,1.29721),(4,1.3229),(5,1.3491),(6,1.37581),(7,1.40306),(8,1.43084),(9,1.43084),(10,1.43084)))	/	Dmnl
69	**multiple cropping index** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,1.81781),(2,1.83181),(3,1.84609),(4,1.86066),(5,1.87552),(6,1.89068),(7,1.90614),(8,1.9219)，(9,1.9219)，(10,1.9219)))	/	Dmnl
70	**minimum retained irrigated area** = minimum sown area of irrigated land/(multiple cropping index*ratio of food to cash crop acreage)	/	ha
71	**minimum retained irrigation water demand** = "#comprehensive irrigation quota for grain crops"*minimum retained irrigated area/0.6	The value 0.6 represents the effective utilization coefficient of irrigation water.	m^3
72	r**igid water demand for irrigation of grain crops** = minimum retained irrigation water demand/10000	/	10^4m^3
73	**stratified proportion of agricultural irrigation water demand** = rigid water demand for irrigation of grain crops/water demand for irrigation of grain crops	/	Dmnl
74	r**igid water demand for irrigation of forestry** = stratified proportion of agricultural irrigation water demand*water demand for irrigation of forestry	/	10^4m^3
75	**agricultural rigid water demand** = rigid water demand for irrigation of grain crops+rigid water demand for irrigation of forestry	/	10^4m^3
76	**medium-sized reservoirs water availability** = 1593.16-273	The value 273 represents the environmental flow demand.	10^4m^3
77	**reservoir reoperation index** = 1.28	/	10^4m^3
78	**beneficial reservoir capacity** = 1104.62	/	10^4m^3
79	**small-sized reservoirs water availability** = beneficial reservoir capacity*reservoir reoperation index	/	10^4m^3
80	**surface water availability** = "medium-sized reservoirs water availability"+"small-sized reservoirs water availability"	/	10^4m^3
81	**south-to-north water diversion water availability** = STEP(2000, 3)	/	10^4m^3
82	**groundwater availability** = 7926	/	10^4m^3
83	**coal mine drainage** = 3513.69	/	10^4m^3
84	**industrial effluent conversion coefficient** = 0.47	/	Dmnl
85	**domestic sewage conversion factor** = 0.8	/	Dmnl
86	**sewage treatment reuse rate** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,0.433),(10,0.433)))	/	Dmnl
87	**#sewage treatment reuse rate** = IF THEN ELSE("α1.5"*sewage treatment reuse rate>=0.6, 0.6 , "α1.5"*sewage treatment reuse rate)	The value 0.6 serves as the upper feedback control limit for the sewage treatment reuse rate.	Dmnl
88	**sewage collection coefficient** = WITH LOOKUP(Time,([(0,0)-(10,10)],(1,0.9),(10,0.9)))	/	Dmnl
89	**#sewage collection coefficient** = IF THEN ELSE("α1.5"*sewage collection coefficient>=0.95,0.95,"α1.5"*sewage collection coefficient)	The value 0.95 serves as the upper feedback control limit for the sewage collection coefficient.	Dmnl

	Formulas	Note	Units
90	**recycled water availability** = IF THEN ELSE(((0.204844*industrial water demand*industrial effluent conversion coefficient+0.329187*urban domestic water demand*domestic sewage conversion factor)*"#sewage collection coefficient"*"#sewage treatment reuse rate")>=960,960,((0.204844*industrial water demand*industrial effluent conversion coefficient+0.329187*urban domestic water demand*domestic sewage conversion factor)*"#sewage collection coefficient"*"#sewage treatment reuse rate"))	The value 960 represents the annual treatment capacity limit for the reclaimed water treatment plant.	10^4m^3
91	**unconventional water availability** = coal mine drainage+recycled water availability	/	10^4m^3
92	**total water supply** = "south-to-north water diversion water availability"+groundwater availability+surface water availability+unconventional water availability	/	10^4m^3
93	**rigid water scarcity rate** = ACTIVE INITIAL(rigid total water demand-total water supply)/rigid total water demand	initial value=0	Dmnl
94	SAVEPER = TIME STEP	/	Dmnl
95	INITIAL TIME = 1	/	Dmnl
96	FINAL TIME = 10	/	Dmnl
97	TIME STEP =1	/	Dmnl

Table S2. Actual and simulated values of each typical variable for the validation period 2020-2022 in Wu'an.

Variables	Historical values			Predicted Values		
	2020	2021	2022	2020	2021	2022
total population (person)	811631	816496	821390	811709	814556	817439
industrial value added (CNY 10^4)	375.99	387.79	399.96	359.55	420.51	420.18
industrial water demand (10^4m^3)	8327.18	9507.73	9650.06	7963	10310	10138
domestic water demand (10^4m^3)	2439.39	2467.78	2495.22	2250	2554	2562
agricultural water demand (10^4m^3)	1887.77	2148.21	2596.81	1457	2596	2659
ecological water demand (10^4m^3)	156.67	161.87	166.81	150.1	150.3	150.4
total water demand (10^4m^3)	12811.01	14285.6	14908.9	11820	15610	15509