

Replication of the Pampa Irrigation System model

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ODD protocol

Purpose

This is a replication of the Pampa model that simulates the Pampa Irrigation System in Nepal (Cifdaloz et al., 2010). The purpose of this model is to analyze the robustness of this small-scale irrigation system to two scenarios of disturbances to the natural resource (discharge reduction and time shift in water supply), and two scenarios of disturbances to the physical infrastructure (canals and gates) using five possible irrigation policies (open flow, sequential rotation, optimized sequential, 24-hour rotation, and 12-hour rotation).

Entities, state variables, and scales

The entities of the model are six irrigation sectors of rice, each covering 11.67 ha. Sectors differ in their location (Fig. 1). To divert water to cultivated areas, systems make use of headworks, canals, and water allocation. There are four major branches in the canal system with different longitude (Fig. 1, Table 1). The values of the main parameters used in this model are showed in Table 1. One time step in the model is one day.

Figure 1. Block diagram of the Pampa irrigation system (adapted from Cifdaloz et al., 2010). Numbers represent the irrigation sectors and letters represent the major branches in the canal system. The arrows show the direction of the water flow.

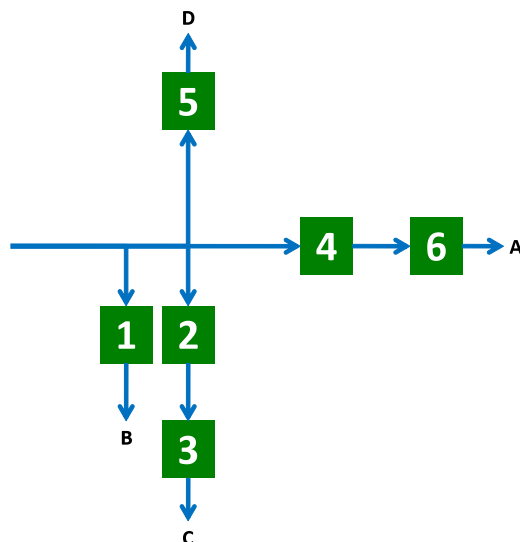


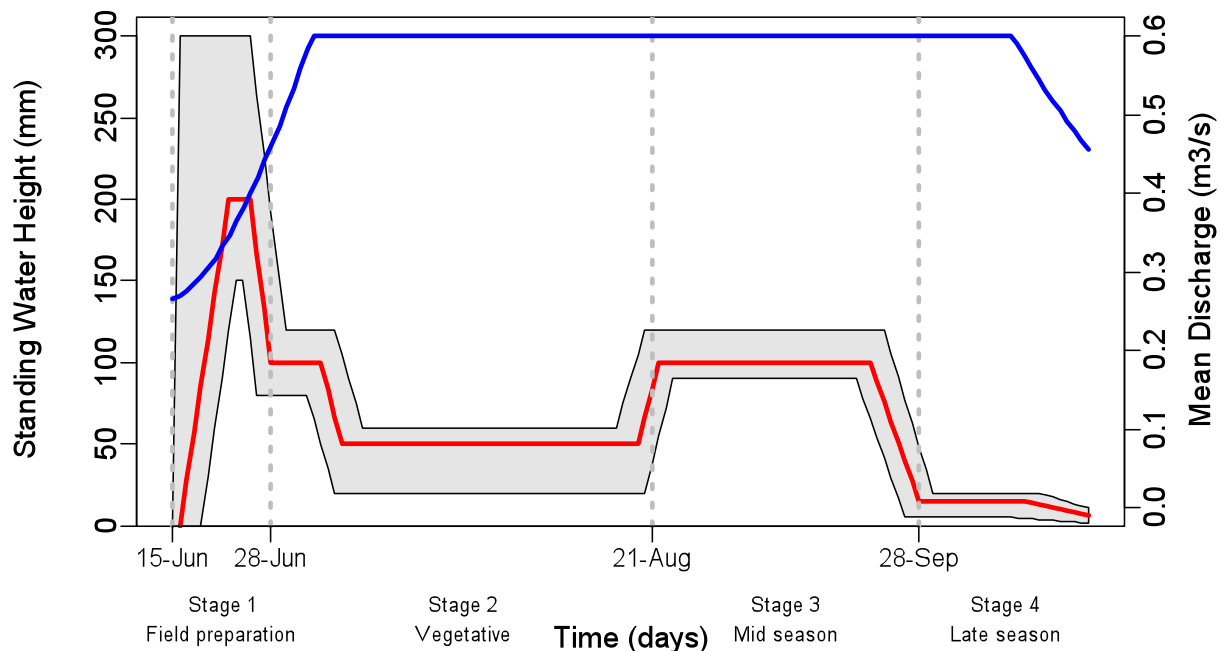
Table 1. Definitions and values of variables and parameters used in the model.

Parameter	Description	Value
A	Area of each sector (ha)	11.67
$stress$	The cumulative water stress is the area between the actual and the desired water height (mm).	≥ 0
w	Reduction in the river discharge volume (%)	0-1
dis	Distance to water source (m). This distance is used to determine the amount of water loss. In the open flow policy, 700 m of the canal are continuously impacted by water leaking.	Sector 1 = 950 Sector 2 = 950 Sector 3 = 1450 Sector 4 = 950 Sector 5 = 1200 Sector 6 = 1450
ϕ	Evapotranspiration (m^2/s)	0.02
t_s	Time shift in river discharge (days)	0-32
$time$	Number of days needed to repair the infrastructure to allow for a portion of the water to flow into the system (days)	0,5,8
Y	Yield produced by each sector during one irrigation season	0-100
u	Water flow (m^3/s)	≥ 0
$loss$	Water loss in the canals ($m^3/day/100m$)	0-4
y	Standing water height (m)	0-200

Process overview and scheduling

The cultivation process comprises five stages: nursery, field preparation and transplant, vegetative, midseason (reproductive stage), and late season (ripening stage) (Fig. 2). Each season, requires a certain amount of standing water (Fig. 2). Field preparation and midseason stages are relatively more sensitive to water shortages than the vegetative stage and the late season.

Figure 2. Desired water level (i.e., demand) and water supply (river regime). Blue line=mean discharge, red line=desired level, gray polygon=desired supply level range.



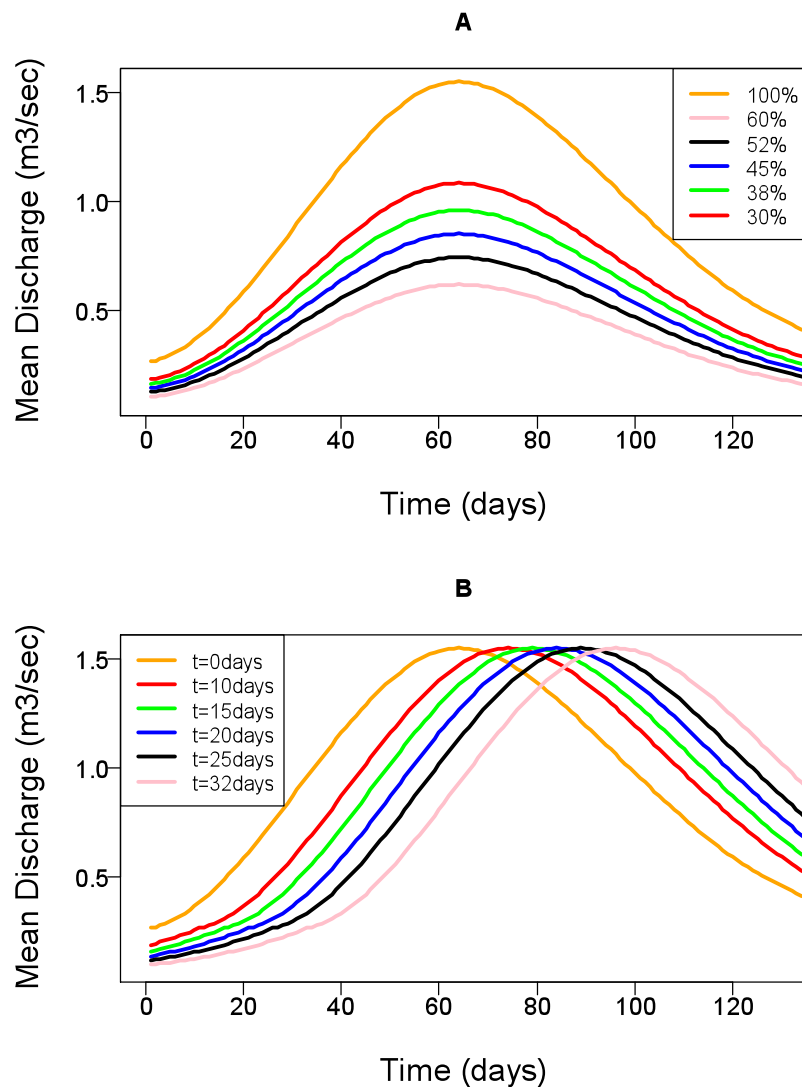
Every day, the next 3 steps are done:

1. Water flows through the canals

The water available to irrigate depends on the disturbance scenarios:

- Scenarios of disturbances to the natural resource are related with climate change:
 - River discharge reduction: mean rainfall is reduced, resulting in lower river flows (Fig. 3).
$$u = u - u * w$$
, where w is the reduction in the river discharge volume (u)
 - Time shift: temporal shifts (t_s , days) in precipitation patterns and discharge in the river (Fig. 3).

Figure 3. (A) River discharge volume scenarios. Lines represent different percentage of nominal river flow, (B) Time-shifted mean river discharge scenarios.



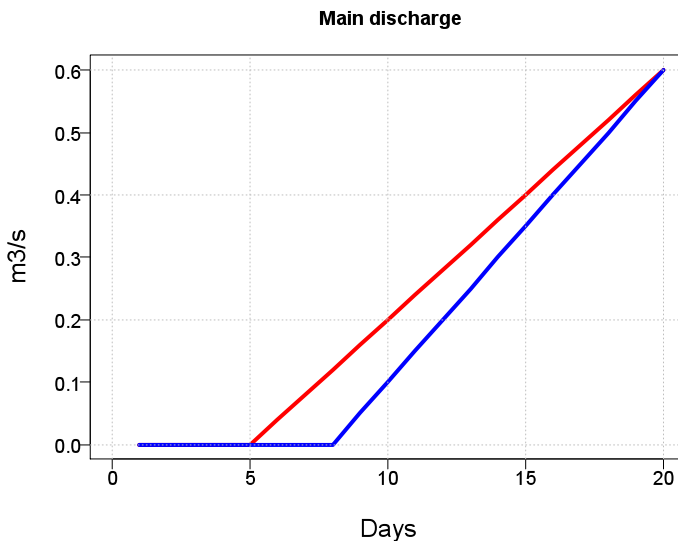
- Scenarios of disturbances to the physical infrastructures (canals and gates):

- Canal maintenance: With this scenario the water loss rate in the canal is increased up to 4l/s/100m.

$u = u - dis * 0.01 * loss$, where u is the river discharge volume, dis is the distance to water source and $loss$ is the water loss in the canals.

- Shock to headgate infrastructure: A shock to the infrastructure in the form of a complete washout of the diversion structures occurs early in the midseason, when river flow rate is highest (Fig. 2). In this scenario, two options are simulated: i) by the 5th day infrastructure is sufficiently repaired to allow for a portion of the water to flow into the system, and ii) it takes 8 days for this to occur. As work proceeds, flow increases steadily and by the 20th day, the canal flow is restored to the nominal flow capacity (0.6m³/s) (Fig. 4).

Figure 4. Two scenarios of water flow as repairs to headgate are made. Red line=5 days repair time, blue line=8 days repair time.



2. Each sector irrigates their field

Each sector irrigates following the rules established by the irrigator community. There are five possible policies, three based on flow and two based on time:

- Open flow: All irrigation gates are open at the same time.
- Sequential rotation: Only one gate is open at any given time. First, sector 1 fills to the nominal demand (Fig. 2), then sector 2, and so on until sector 6. The goal of this policy is to increase the flow rate in the canal system by reducing the total canal area in use at any point in time.

- Optimized sequential: As in the previous policy, but each sector fills to the minimum required (Fig. 2).
- 24-hour rotation: Each sector, starting with sector 1, has its gate open for periods of 24 hours.
- 12-hour rotation: Each sector, starting with sector 1, has its gate open for periods of 12 hours.

The water available to each sector depends on the disturbance scenario, the irrigation policy and the position of the sector. After each sector is irrigated, water covering the fields evaporates:

$y=(U-y^*)/A$, where y is the standing water height (m), U is the amount of water used per time to irrigate a section, A represents the area of a sector, and ϕ represents evapotranspiration.

3. Yield is calculated

Yield depends on the water level. Sufficient water means that the water level remains within the bounds shown in Fig. 2. If a drought or flood occurs the actual water level will fall outside the desired band. The longer the drought or flood, the longer the actual water level will remain outside the band. The yields (Y) are penalized depending on the cumulative water stress (*stress*) using the next function:

$$Y=(y+\pi/2)/(y0+\pi/2)$$

Where $y=\text{atan}(-\alpha*\text{stress}-\beta)$, and $y0=\text{atan}(-\alpha*-\beta)$

The impact of a drought on the yield differs depending on the stage of the growth cycle. Field preparation and midseason stages are relatively more critical than the vegetative stage and late season (Fig. 2). These differences are captured in the model by using different values of *alpha* and *beta* (Fig. 5, Table 2).

Figure 5. Performance measure coefficient functions for droughts.

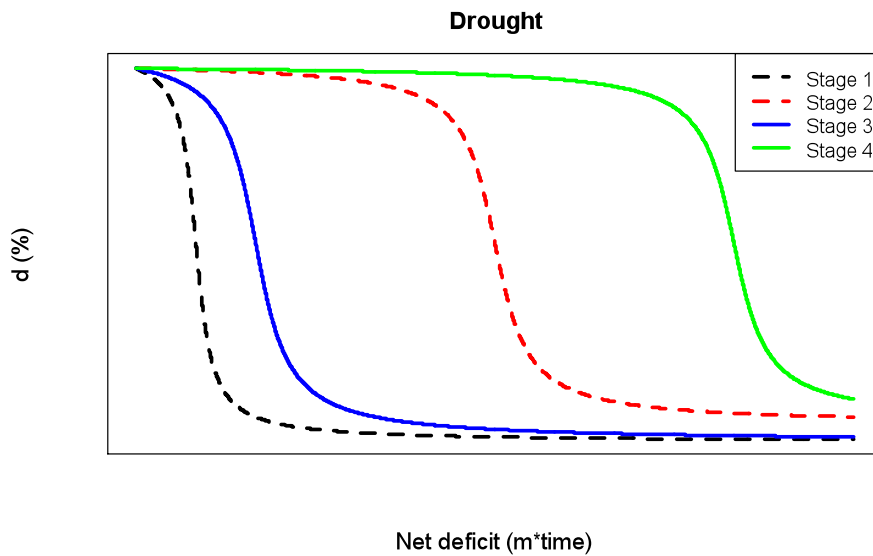


Table 2. Alpha and beta values used to calculate the yield during each season for flood and drought periods.

Stage	Flood		Drought	
	α	β	α	β
1: Field preparation and transplantation	0.10	150	0.10	50
2: Vegetative stage	0.05	300	0.05	300
3: Midseason	0.05	200	0.05	100
4: Late season	0.05	500	0.05	500

The overall efficiency of the irrigation system (% of yield), d , is the product of the efficiencies of all four stages:

$$d=d1 \cdot d2 \cdot d3 \cdot d4$$

The actual yield with respect to the foreseen maximum yield (y_{\max}) is:

$$Y=Y_{\max} \cdot d$$

The sensitivity of the system is a measure of how much yield decreases when water availability deviates from nominal conditions.

Design concepts

Emergence: The water depth and yield of each sector are emergent properties of the systems.

Adaptation: Agents do not actively adapt.

Objectives: Fitness of agents is the water depth of the fields and the yield. If sectors do not get enough water during specific periods of time their yield would be reduced.

Interaction: Water available to each sector depends on the disturbance scenario, the irrigation policy and the position of the sector.

Stochasticity: There is no stochasticity in the model.

Observation: To evaluate the model output, we observe the water depth and yield of each sector as well the total yield for the six sectors.

Initialization

Simulations are initialized with 6 agents (irrigator sectors) located in line and to a distance of dis to the water source. The model concentrates on the field preparation and transplantation stage (Fig. 2, Table 3) since water supply far exceeds demand in all stages but this one. The model concentrates on this stage given that it offers the greatest potential for conflict between supply and demand. Thus, each simulation

consists of 21 time steps, from June 15th to July 5th except for the shock to head-gate infrastructure in which the midseason is simulated.

Input

The following data files are imported.

- WaterDemand.txt: Desired water level (mm) during the field preparation and transplantation stage for the open flow policy (*wdemand*)
- maxWaterDemand.txt: Upper limit of the desired water level (mm) during the field preparation and transplantation stage (*max-wdemand*)
- minWaterDemand.txt: Lower limit of the desired water level (mm) during the field preparation and transplantation stage for the open flow policy (*min-wdemand*)
- seqDemand.txt: Desired water level (mm) during the field preparation and transplantation stage used in the sequential and rotation policies (*seqwdemand*)
- seqMinDemand.txt: Lower limit of the desired water level (mm) during the field preparation and transplantation stage used in the sequential and rotation policies (*seqminwdemand*)
- totannual-wdischarge.txt: Daily water discharge (m³/s) during the stages 1-4 of the irrigation season (*totannual-wdischarge*)
- WaterDemand-s3.txt: Desired water level (mm) during the midseason stage used for the open flow policy (*wdemand-s3*)
- maxWaterDemand-s3.txt: Upper limit of the desired water level (mm) during the midseason stage used in the open flow policy (*max-wdemand-s3*)
- minWaterDemand-s3.txt: Lower limit of the desired water level (mm) during the midseason stage for the open flow policy (*min-wdemand-s3*)
- seqWaterDemand-s3.txt: Desired water level (mm) during the midseason stage for the sequential and rotation policies (*seqwdemand-s3*)

References

Cifdaloz O., Regmi A., Anderies J.M., Rodriguez A.A. 2010. Robustness, vulnerability, and adaptive capacity in small-scale social-ecological systems: The Pampa Irrigation System in Nepal. *Ecology and Society* 15(3): 39. [online] URL: <http://www.ecologyandsociety.org/vol15/iss3/art39/>

Implementation

Below we compare the NetLogo simulations with the results of the original paper (Cifdaloz et al., 2010).

Figure 6. Water depth of sector 1 under the open flow policy for the different discharge scenarios. Gray area: desired supply level. W = percentage of the total of water discharge. Left: original figure by Cifdaloz et al. (2010), right: results of the NetLogo simulations.

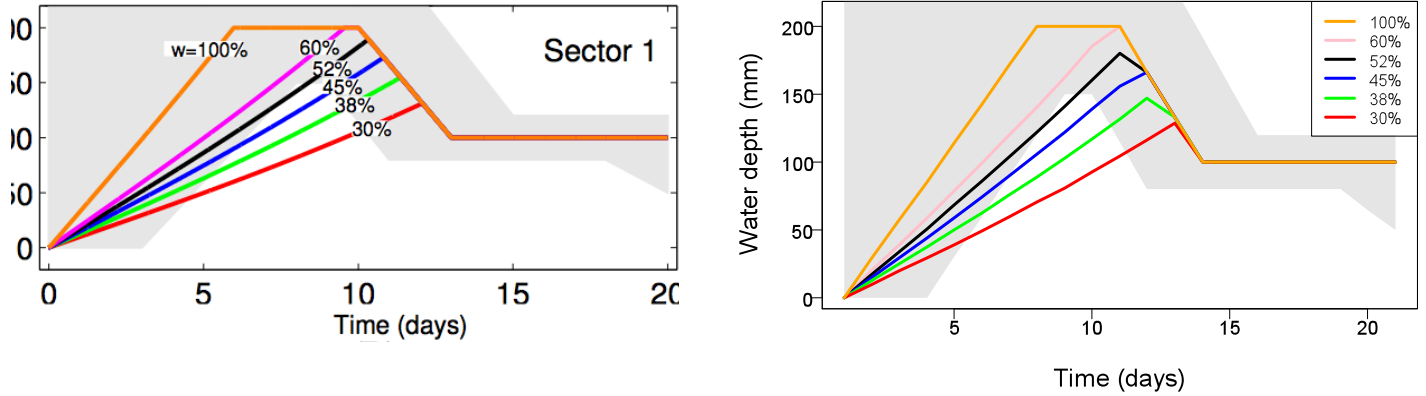


Figure 7. Water depth of all sectors under the sequential policy for the different discharge scenarios. Gray area: desired supply level. The order of the sector of the top figure is the same as in the bottom figure. Left: original figure by Cifdaloz et al. (2010), right: results of the NetLogo simulations.

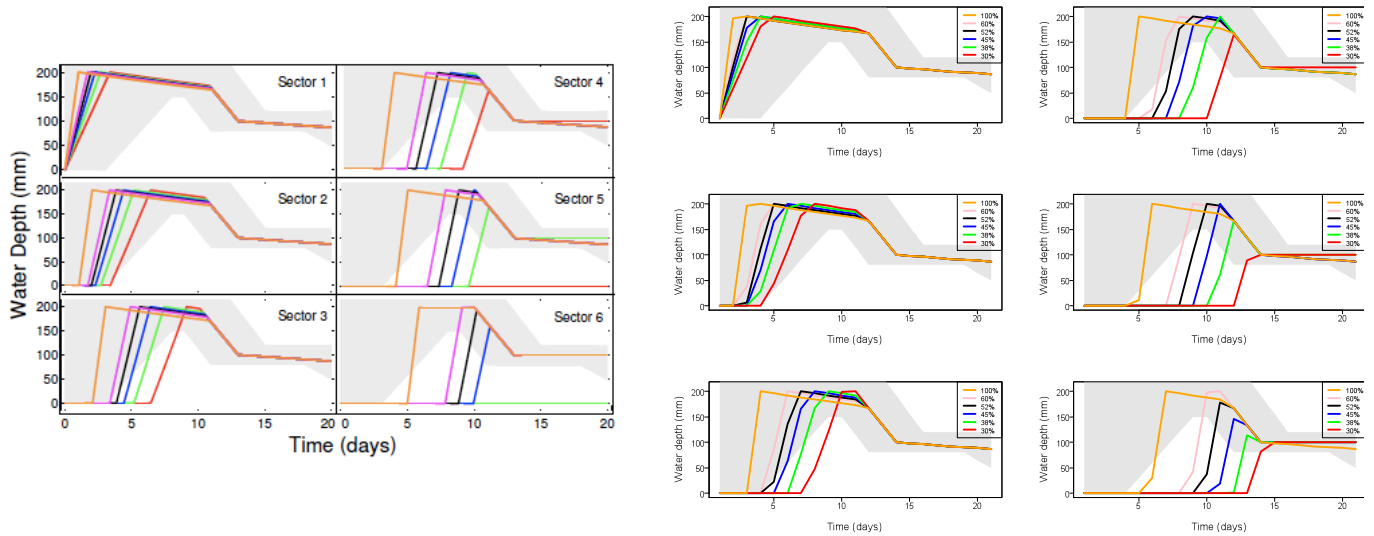


Figure 8. Water depth of all sectors under the optimized sequential policy for the different discharge scenarios. Gray area: desired supply level. The order of the sector of the top figure is the same as in the previous figure. Left: original figure by Cifdaloz et al. (2010), right: results of the NetLogo simulations.

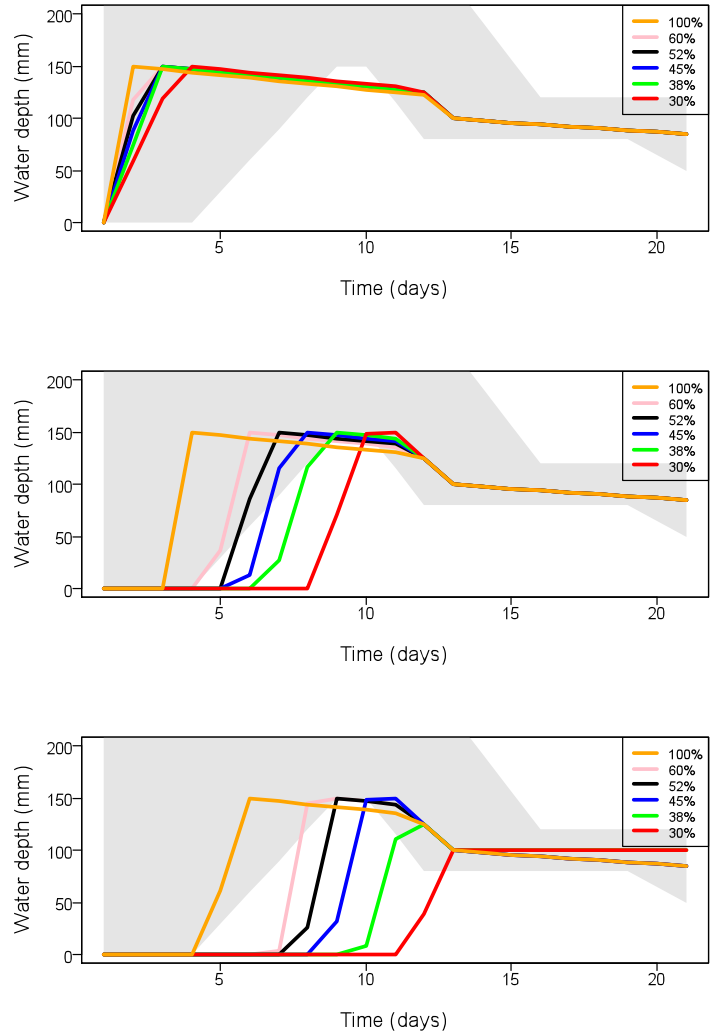
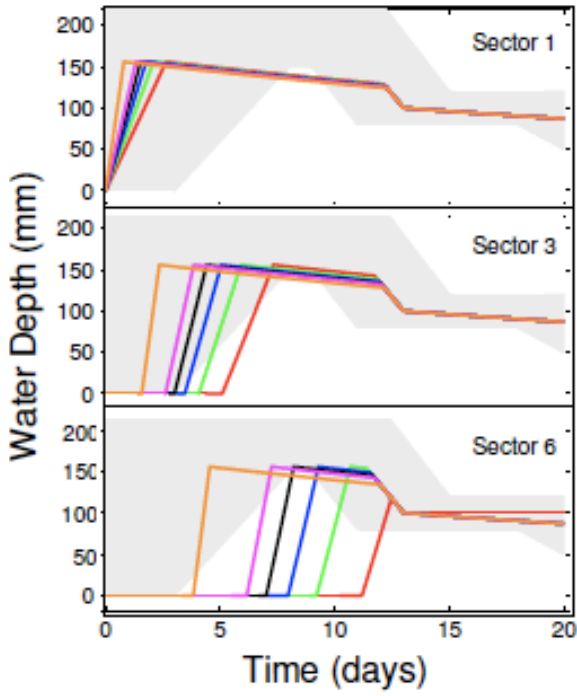


Figure 9. Water depth under the 12-hour and 24-hour rotation policies for the different discharge scenarios. Left: original figure by Cifdaloz et al. (2010), right: results of the NetLogo simulations.

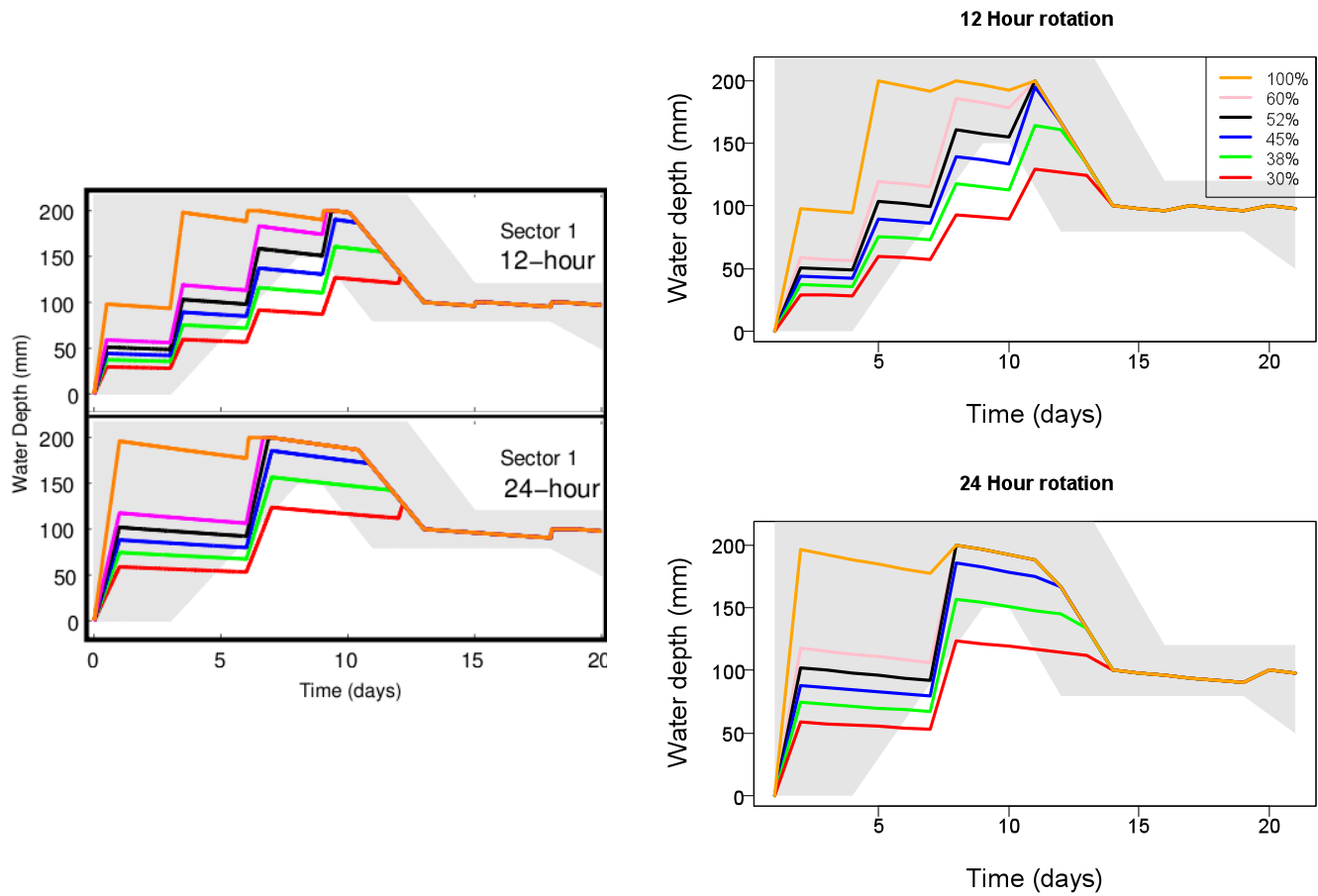


Figure 10. Total yield for the five irrigation policies. Left: original figure by Cifdaloz et al. (2010), right: results of the NetLogo simulations.

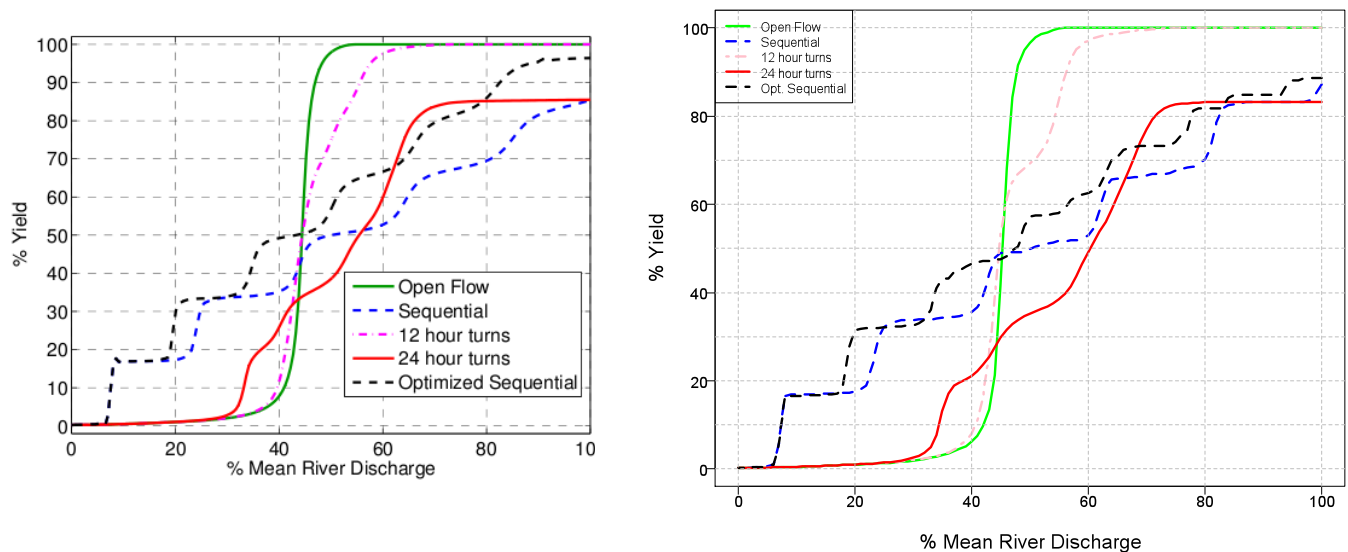


Figure 11. Time-shifted mean river discharge scenarios. Left: original figure by Cifdaloz et al. (2010), right: results of the NetLogo simulations.

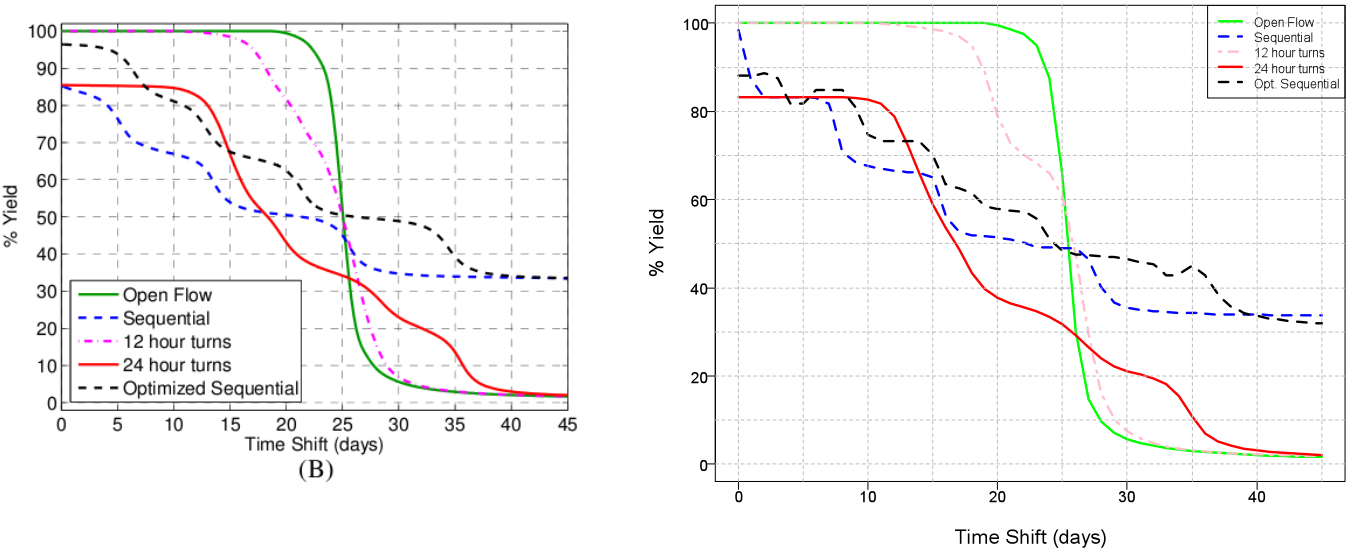


Figure 12. Yield for the five irrigation policies when water losses in the canal are introduced. Top: original figure by Cifdaloz et al. (2010), bottom: results of the NetLogo simulations.

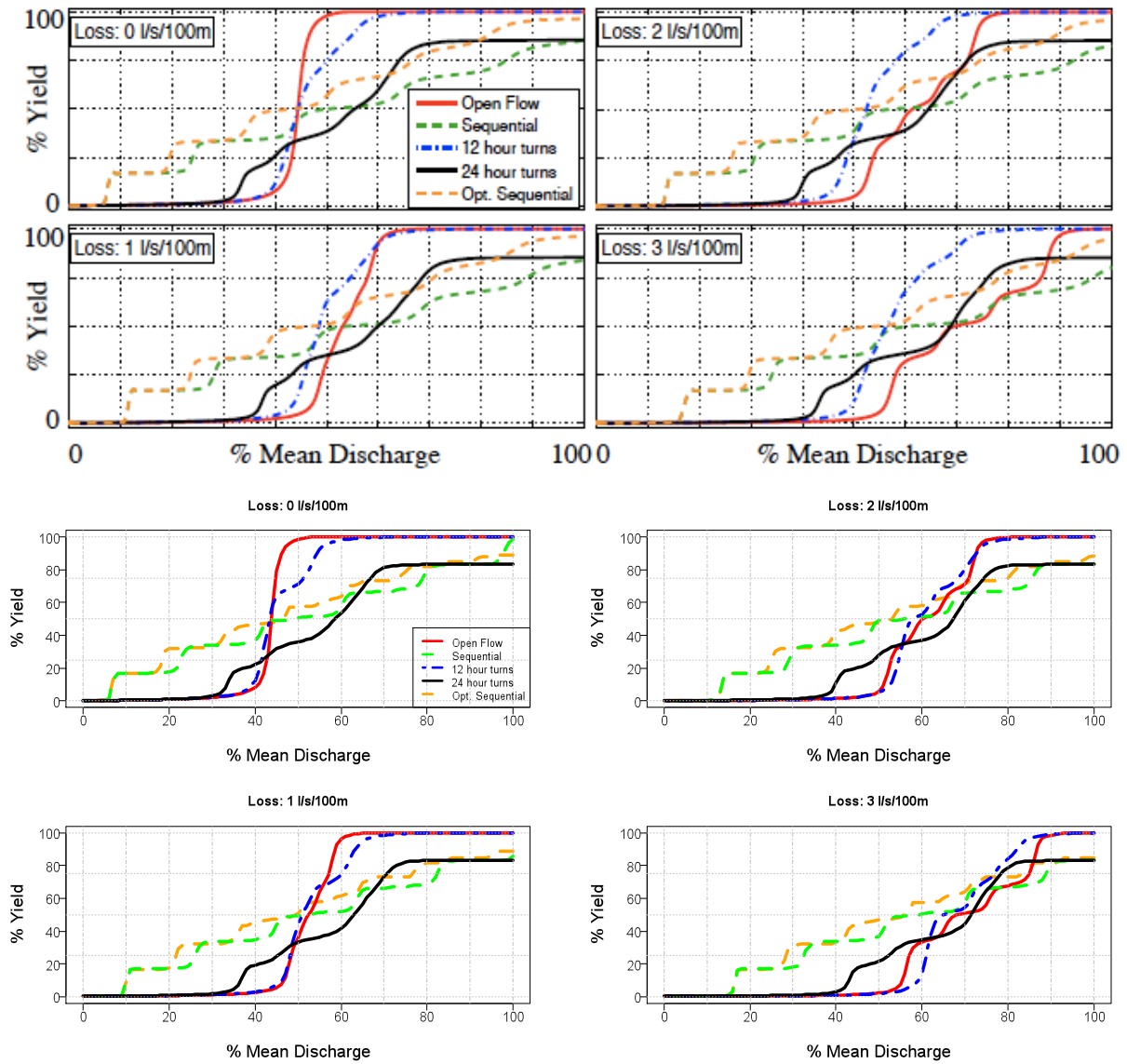


Figure 13. Water depth after a shock to headgate infrastructure. The order of the sectors of the top figure is the same as in the bottom figure. Top: original figure by Cifdaloz et al. (2010), bottom: results of the NetLogo simulations.

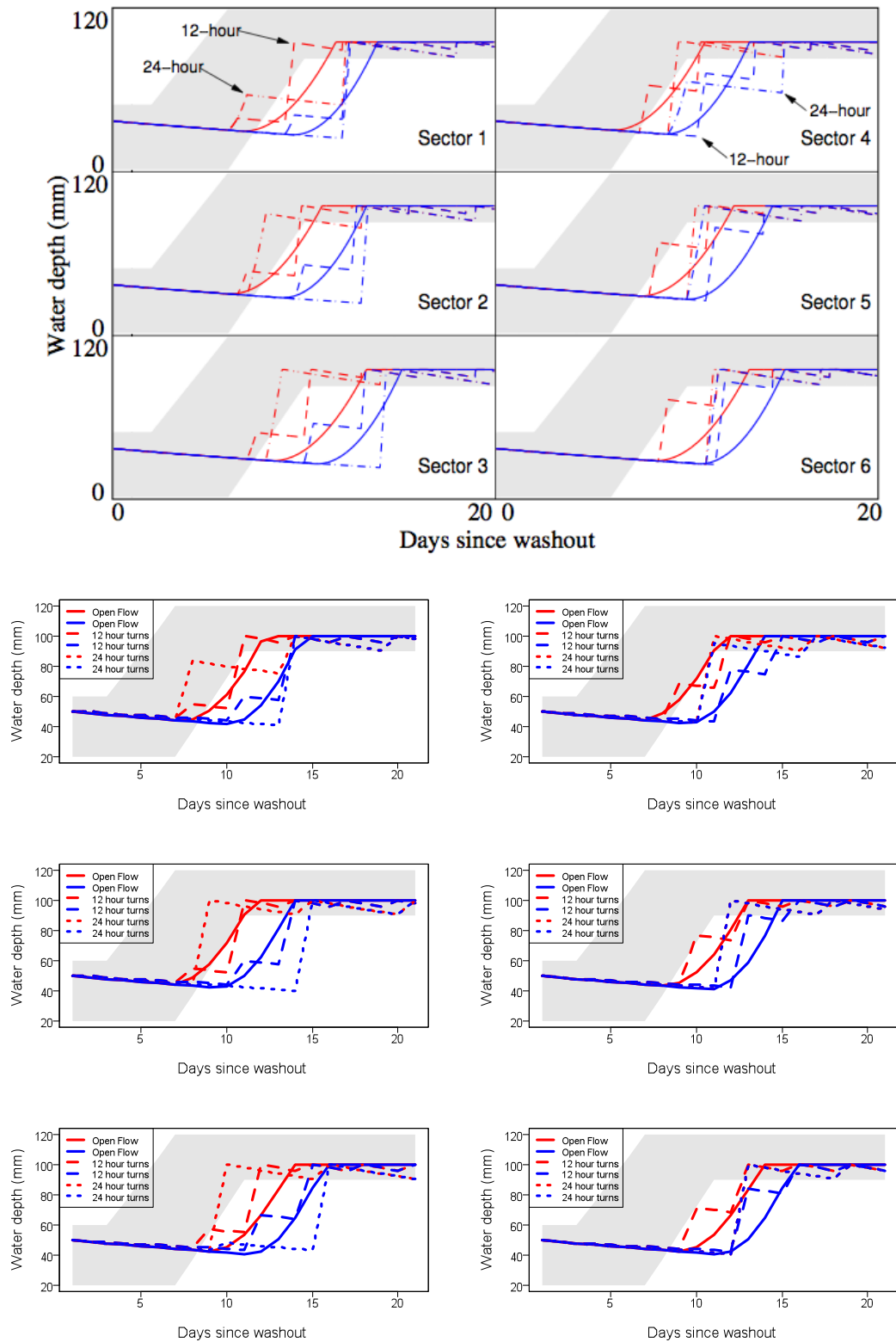


Table 3. Comparison of policy performance given a serious shock to headwork infrastructure during the midseason. Top: original table by Cifdaloz et al. (2010), bottom: results of the NetLogo simulations.

Shock	Policy	Yield, percent of maximum							Gini
Scenario	Response	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Mean	Coeff.
Red	Open Flow	93.88	98.62	21.09	98.62	71.95	21.09	67.54	0.26
	Sequential	95.29	96.53	95.07	89.95	76.68	47.45	83.50	0.10
	12-hour	98.60	98.33	96.81	98.08	97.35	96.14	97.55	0.01
	24-hour	80.78	99.71	99.58	97.06	83.59	23.95	80.78	0.15
Blue	Open Flow	9.63	15.80	5.05	15.80	6.67	5.05	9.67	0.26
	Sequential	88.84	34.55	14.48	9.34	7.15	5.85	26.70	0.52
	12-hour	16.53	17.28	12.73	17.58	14.66	12.42	15.20	0.08
	24-hour	8.83	5.42	3.89	14.15	73.05	20.10	20.91	0.53

Scenario	Policy	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Mean	Gini
Red (time repair = 5 days)	Open flow	84.92	95.95	12.41	95.95	35.24	12.41	56.15	0.36
	Sequential	100	99.66	99.02	97.56	92.28	87.97	96.08	0.02
	12-hour	91.96	91.96	64.04	90.67	78.25	56.2	78.85	0.1
	24-hour	93.93	99.22	95.81	72.61	17.4	7.87	64.47	0.31
Blue (time repair = 8 days)	Open flow	7.4	10.25	4.33	10.25	5.34	4.33	6.98	0.2
	Sequential	93.4	70.89	41.17	16.2	13.54	12.53	41.29	0.4
	12-hour	8.87	8.87	6.5	9.38	8	6.72	8.06	0.07
	24-hour	5.2	3.75	3.31	64.72	17.4	7.87	17.04	0.57