Appendix 2: Shock scenarios

Shocks were applied to the P-GBSDM in order to assess the response of the three study variables to varied levels of disturbance. In an effort to simulate response trajectories under the most realistic circumstances, shock scenarios were selected from both a socioeconomic and environmental domain. The following two shock types were used: 1) Increased market inflation, and 2) Decreased canal water supply. These shocks were selected based on their connectivity to most adjacent variables within the system, making their impact on the study variables particularly influential. The selected shock scenarios also represent both the socioeconomic and biophysical capabilities of the coupled model, thereby producing the most reliable and realistic results for each run; i.e. these shocks are two of the most prevalent disturbance scenarios in semi-arid agricultural basins like the Rechna Doab watershed. Each shock was applied to the model individually (i.e. compound shocks were not employed in this study) with varying magnitudes of intensity and duration. The discrete application of the shock scenarios allows for a better understanding of the precise influence a specific disturbance event may have on the resilience of an individual variable, thereby allowing for a more accurate assessment of each variables' unique vulnerabilities and enhancing the opportunity for more effective, targeted legislative or organizational counter-measures. The inflation shock was applied as an increase in Pakistan's documented annual inflation (values of x2, x5, x10, and x15 with respect to market data collected for the year 2003) (Pakistan Bureau of Statistics, 2020). 2003 was selected as the reference year due to the comparatively high amount of consistent, reliable socioeconomic data collected by the Government of Pakistan for that year; as such, 2003 was used as the market inflation reference year for the original incorporation of this variable into the P-GBSD model. Intensity values for the inflation shock were initially determined by examining historical inflation trends in Pakistan. According to the World Bank, Pakistan's highest inflation rate on record occurred in 1974, with a rate of 26.7%; this is a nearly ten-fold difference from the rate of 2.9% documented in 2003; as such, the inflation shock factors were selected based on the extreme historical values experienced in Pakistan (IMF, 2019). Outputs from the coupled model support the general socioeconomic data trends in the region which indicate that market inflation is greatly influenced not only by societal or political fluctuations, but to an even greater extent by the state of agroecological variables such as crop yield, soil salinity, and water-table depth, among others. In other words, with the exception of a catastrophic event akin to the declaration of civil war, a bad crop year tends to elicit more cascading socioeconomic repercussions than a change in agricultural policy or social practice. The canal supply shock was applied as a decrease in canal water supply of 10%, 25%, 50%, and 90%; these values were selected based on historical precipitation and water use patterns in the Rechna Doab and were subsequently tested using a manual shock testing methodology in the participatory-built model drafted in Vensim. The manual shock testing in Vensim resulted in canal supply outputs supporting the claims that increasingly frequent and severe drought in the region coupled with high soil salinity and sub-par water management infrastructure can lead to increased instances of reduced canal water supply in the Rechna Doab watershed (Inam et al., 2015; World Bank, 2020). Each shock intensity was 'held' in the model for periods of one, five, ten, or twenty years; in other words, each shock type was run for 16 different intensity and duration scenario combinations (32 unique shock combinations for each study variable) (Figure A2.1). The responses of the three study variables to each of the unique shock combinations was analyzed for a period of 30 years between 1989 and 2019. Each shock was initially applied ('turned on') in the final season of the year 1989 and removed in either 1991, 1995, 2000, or 2019, depending on the duration stipulation for that run.

Response data was obtained for the three study variables after each unique shock scenario simulation. In order to ensure a cross-variable, comparative resiliency analysis, each set of response data was normalized to the base-case state of the study variable for that run. In other words, the 'shocked' response data was divided by the normal functionality data for each variable under each disturbance scenario. Each result was normalized to the base-case state of the variable for each individual polygon at each unique time-step, resulting in 215 unique base-case sets of 60 points (i.e. seasons) for each study variable. The normalization process resulted in response data that showed the degree of fluctuation or change experienced by each variable compared to the business as usual state. This normalized data was suitable for resilience metric calculation without fear of the variation in system units altering the comparability of the final resiliency outputs. Figure A2.1 shows an example of the shock intensity/duration combinations applied to each of the study variables. The outputs change dynamically over time, i.e. the values fluctuate over the course of the 30-year evaluation window, but the model is not stochastic and subsequent runs of the same data sets return identical output patterns. The inherent replicability of the output values in this methodology precluded the need for an uncertainty analysis.

	Shock 1 (Inflation)				Shock 2 (Canal Supply)			
INTENSITY	X2	X5	X10	X15	10%	25%	50%	90%
DURATION								
1 yr	S1,X2,01	S1,X5,01	S1, X10, 01	S1, X15, 01	S2, 10, 01	S2, 25, 01	S2, 50, 01	S2, 90, 01
5 yr	S1,X2,05	S1,X5,05	S1, X10, 05	S1, X15, 05	S2, 10, 05	S2, 25, 05	S2, 50, 05	S2, 90, 05
10 yr	S1,X2,10	S1,X5,10	S1, X10, 10	S1, X15, 10	S2, 10, 10	S2, 25, 10	S2, 50, 10	S2, 90, 10
20 yr	S1,X2,20	S1,X5,20	S1, X10, 20	S1, X15, 20	S2, 10, 20	S2, 25, 20	S2, 50, 20	S2, 90, 20

Fig. A2.1. Shock type (S1: Inflation, S2: Canal Supply), intensity (x2, x5, x10, x15 (factor with reference to base-case inflation) and 10, 25, 50, 90 (% reduction in canal water supply), and duration (01, 05, 10, 20 (in years)) combinations for each of the three interest variables