Farmponds for Horticulture: Boon or Curse? Analysing Impact on Farm Profitability, Resource Sustainability and Social Welfare

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Abstract

Plastic lined farmpond, used to store groundwater for use in scarcity period, is currently a topic of much debate in Indian agriculture. Some regard it as a miracle drought-proofing tool which enables farmers to increase their income. Others consider it an unsustainable tool that allows some farmers to exploit a scarce resource at the cost of others. This paper offers a system dynamic analysis of farmponds in terms of their hydrological, economic and social impact. Farmers invest in farmponds in response to groundwater uncertainty and economic gain from shifting to water intensive high-value crops. As more farmers build new farmponds attracted by the success of the initial adopters and change their cropping pattern, groundwater extraction exacerbates causing further uncertainty in groundwater availability. The non-farmpond owners are particularly impacted pushing even more of them towards investing in farmponds. As this cycle continues, eventually even the farmpond owning farmers are impacted making everyone worse off compared to the initial state. The paper shows that it is unlikely that a desired state of equilibrium can be achieved without regulation because economic incentives continue to drive farmers to invest in farmponds even as groundwater levels fall thereby leading to the tragedy of the commons.

Word Count: 6935 words

1. Introduction

India has more than half of its workforce engaged in agriculture but the share of agricultural output in the country’s GDP is only 15%. There is a strong policy push for increasing agriculture productivity and farm incomes. One of the ways in which this is being pursued is by promoting high value horticulture crops (i.e. vegetables and multiyear fruit crops) (Government of India 2015). Land under horticulture has nearly doubled in the past two decades. Since 2012-13, the total horticulture production (at 268.9 million MT) has surpassed the production of food grains (at 257.1 million MT) in India (Government of India, 2016).

Maharashtra is one of the leading states in horticulture production. Various government schemes such as the early Employment Guarantee Scheme and subsequently the National Horticulture Mission have promoted horticulture production (Government of India, 2014). Maharashtra is also a drought prone state and has witnessed rising agrarian distress evident from a large number of farmer suicides. This has been attributed to many factors including climate change and increasing water stress (Reddy and Mishra 2009).

Horticulture production tends to be input intensive and very sensitive to availability of timely irrigation. Ground water (GW) is the primary source of irrigation supporting 71% of area under irrigation in the state. During scarcity periods, there is high uncertainty in the availability of ground water. Hence, horticulture farmers often make large investments in water infrastructure in order to assure availability during scarcity months. One type of structure that has gained tremendous popularity in the past decade is the “farm pond”. Farm ponds are privately- owned ponds that are dug out in the fields and are filled using surface run off or ground water during the rainy season. Farm ponds used with horticulture are used as storage structures – they are lined using a plastic sheet which prevents percolation into the ground. The focus of this paper is the ground-water filled farm pond which is used extensively in many parts of Maharashtra primarily for irrigating horticulture crops.

Responding to the immense popularity of farm ponds, the government of Maharashtra has promoted them through various programs including the National Horticulture Mission and “*Magel tyala shettale*” (farm pond for anyone who demands it) which partially subsidise them. Once a farm pond is constructed, it enables a shift in the cropping pattern of the farmer who shifts to cultivating high value water-intensive horticulture crops instead of traditional crops.

On one hand farm pond is seen as a miracle drought-proofing tool which enables farmers to increase their incomes (Ansari 2016, Government of India 2013, Ngigi 2005, Pawar et al. 2012, Wisser, D. 2010) and on the other hand, it is considered to be an exploitative and unsustainable tool that allows farm pond owners to stock up on ground water, a scarce common pool resource (Kale 2017). Moreover, the stored water is subjected to evaporation losses resulting in high inefficiency. The objective of this work is to assess these two views by analyzing the impact of farm ponds along hydrological, agricultural and economic dimensions.

This very real problem naturally lends itself to a system dynamic approach. There are multiple stakeholders involved such as farmers, practitioners, policy makers, politicians, state agencies and regulators. Accordingly, there are multiple goals: to raise farm incomes, to be more drought-resilient, to make judicious use of a scarce resource and to maintain social welfare. Moreover, a dynamic analysis is crucial because farmers respond to situations created by the action of other farmers or stakeholders. Many researchers have used the system dynamics approach to analyse the relation between agricultural development and sustainable water resource management focusing on groundwater (Balali and Viaggi 2015, Niazi et al. 2014) or surface water (Kotir et al 2016). This paper focuses on a very specific and immediate question being faced by the state: Are farm ponds good or bad from the following points of view: farm profitability, resource sustainability and social welfare. Once this is established, various policy levers may be used to achieve the desired state.

The model shows that as more farmers build new farmponds attracted by the success of the initial adopters and change their cropping pattern, groundwater extraction exacerbates causing further uncertainty in groundwater availability. The non-farmpond owners are particularly impacted pushing even more of them towards investing in farmponds. As this cycle continues, eventually even the farmpond owning farmers are impacted making everyone worse off compared to the initial state. The paper shows that it is unlikely that a desired state of equilibrium can be achieved without regulation because economic incentives continue to drive farmers to invest in farmponds even as groundwater levels fall thereby leading to the tragedy of the commons.

The next section provides a brief background on agriculture and groundwater in Maharashtra. This is followed by a conceptual overview and the feedback loops in the system. Section 3 focuses on model setup and baseline calibration. Section 4 describes the modeling the feedback loops. Model results are presented in section 5 followed by discussion and conclusions.

1. 1 Context

There are three farming seasons in the state– Kharif (the monsoon crop from June to September), Rabi (the winter crop from October to February) and the summer season (March – May). Crops differ according to agroclimatic conditions but in the ground water dependent drought-prone regions where farm ponds are being introduced Kharif crops include millets, pulses, cotton or vegetables. Typical Rabi crops include wheat, sorghum, green gram or vegetables such as onions. They are either grown solely on soil moisture or using ground water when available. A significant part of the cultivable land is left fallow in Rabi and even more so in summer due to unavailability of water for irrigation. The most significant horticulture crops include pomegranate, grapes, banana, citrus fruit, tomato and onions.

Fruit orchards are multiyear crops that require access to assured irrigation all-round the year, including the scarcity months of March to June. Since orchards are a multi-year commitment with large investment, farmers often choose to simultaneously invest in farm ponds in order to assure water for irrigation during the summer months. Ponds were traditionally known to be groundwater recharge structures but these farm ponds are storage structures that allow farmers to convert a large quantum of ground water, which is a public good, into a private resource. They are made in varying sizes but the most common ones store about two thousand cubic meter (TCM) water. These are typically built by farmers who are economically strong. Currently, government schemes provide a subsidy ranging from one-third to one-half of the cost.

Maharashtra is one of the few states in the country that has enacted the Maharashtra Groundwater (Regulation for Drinking Water Purposes) Act 1993 and subsequently the Maharashtra Groundwater (Development and Management) Bill 2009 (Government of Maharashtra 1993, 2009). However, there are serious limitations in the enforcement of the Act and in practice there are no constraints on the crop choice and extent of ground water extraction. The large subsidy given on agricultural electricity use also incentivizes ground water development. While there has been a tremendous rise in the number of private farm ponds in the past decade, there is no official process or metric that tracks this number.

2. Conceptual Model

The objective of this work is to analyse the impact of farm ponds from hydrological, economic and social standpoints. The basis of the model is data gathered from field observations and surveys conducted in different parts of the state including districts of Nashik, Ahmednagar, Jalna, Hingoli and Akola.

The model simulates a typical village. The first part of the model only looks at the hydrological aspects. Ground water and surface water (ponds, dams etc.) are the two main stocks. The main flows are rainfall, rainfall runoff, ground water percolation and its extraction. There are other flows which model losses from the stocks or transfer from one stock to another i.e. evaporation from surface sources, subsurface flow of ground water and base flows (sub surface flows that seep out on the surface as springs). Figure 1 shows the relation between them. The flows shown in red are exogenous to the model while the others are computed endogenously using system parameters (e.g. slope, soil type, aquifer properties, cropped area, irrigation requirement etc.) and hydrological relationships between different stocks and flows.

When farm ponds are introduced and filled by ground water extraction, this increases the GW extraction in the model and accordingly affects all other stocks and flows. This part of the model is useful in observing the extent to which groundwater can support extraction to fill farm ponds. It does not have any feedback loops at this stage.

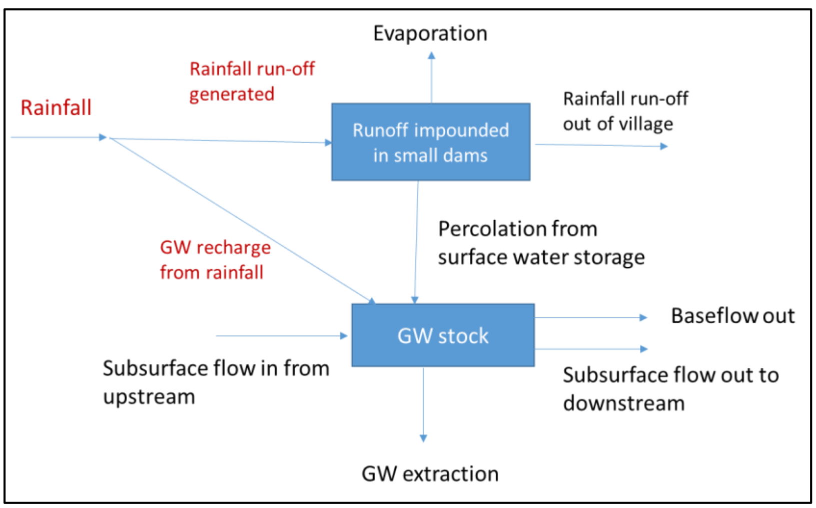


Figure 1: Stocks and flows in the hydrological model

In the second part of the model, a reinforcing loop is modeled. Farm ponds are promoted in regions facing variability in ground water access. Introduction of new farm ponds triggers a change in the cropping pattern as farmers shift from traditional Rabi crops to water intensive Rabi crops such as vegetables or to annual fruit orchards. This change in crop increases the monthly irrigation requirement which is fulfilled by increased ground water extraction for direct irrigation and by farmponds during scarcity periods. This, coupled with the inefficiency of farm ponds due to evaporation losses, further increases ground water extraction. As the groundwater demand rises, not all irrigation demand can be met by groundwater and farmers start to experience greater risk in water availability. This rising uncertainty motivates more farmers to invest in farm ponds in order to secure water for themselves thereby creating a vicious cycle. This is shown in a conceptual flow in Figure 2.

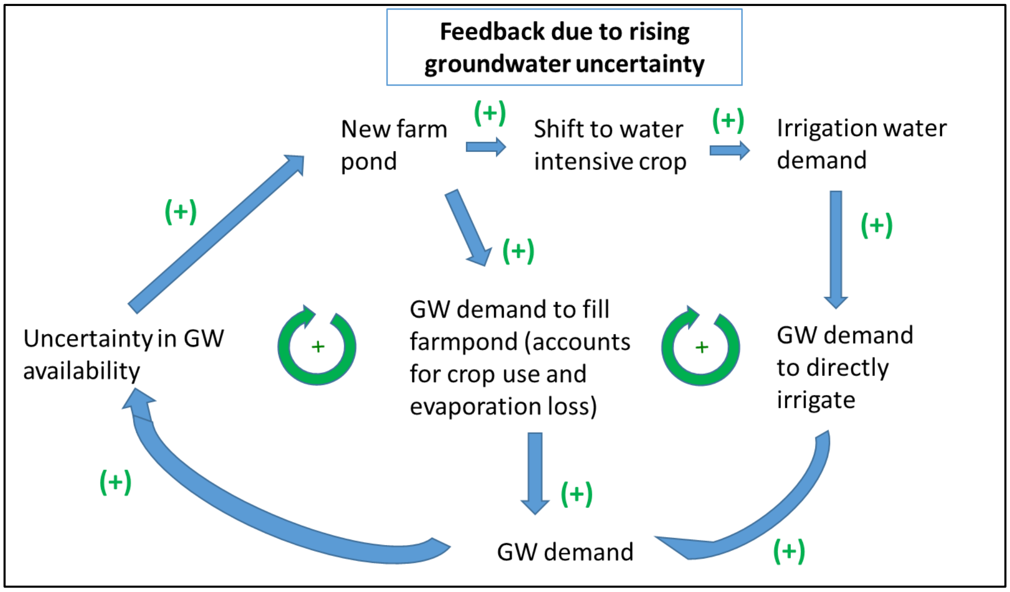


Figure 2: Feedback due to cropping shift and rising groundwater uncertainty

In the third part, an economic layer is added which models another reinforcing loop as well as a balancing loop. This is shown in Figure 3.

As farmers invest in farm ponds, they switch to horticulture crops which have high profitability compared to traditional crops. As farm pond owners make more profit, this incentivizes other farmers to follow suit and reinforces the building of new farm ponds.

When farmers invest in farm ponds, it increases their cost per unit water due to high cost of building and maintaining farmpond. The cost of pumping water is currently negligible in the state due to subsidy for agricultural power feeders but this may be easily incorporated. Increasing cost of water has a reducing effect on profitability. Profitability of farmers also reduces due to another reason. As discussed in previous section, increase in farm ponds increases ground water extraction and after a certain time ground water can no longer meet irrigation demand. At this stage, crop yields suffer and reduce the farmer's profitability. Reduced profitability of farm ponds owners makes investment in farm ponds less attractive to other farmers. This is the balancing loop which works to stabilize the number of farm ponds.

The next section goes through the details of model setup.

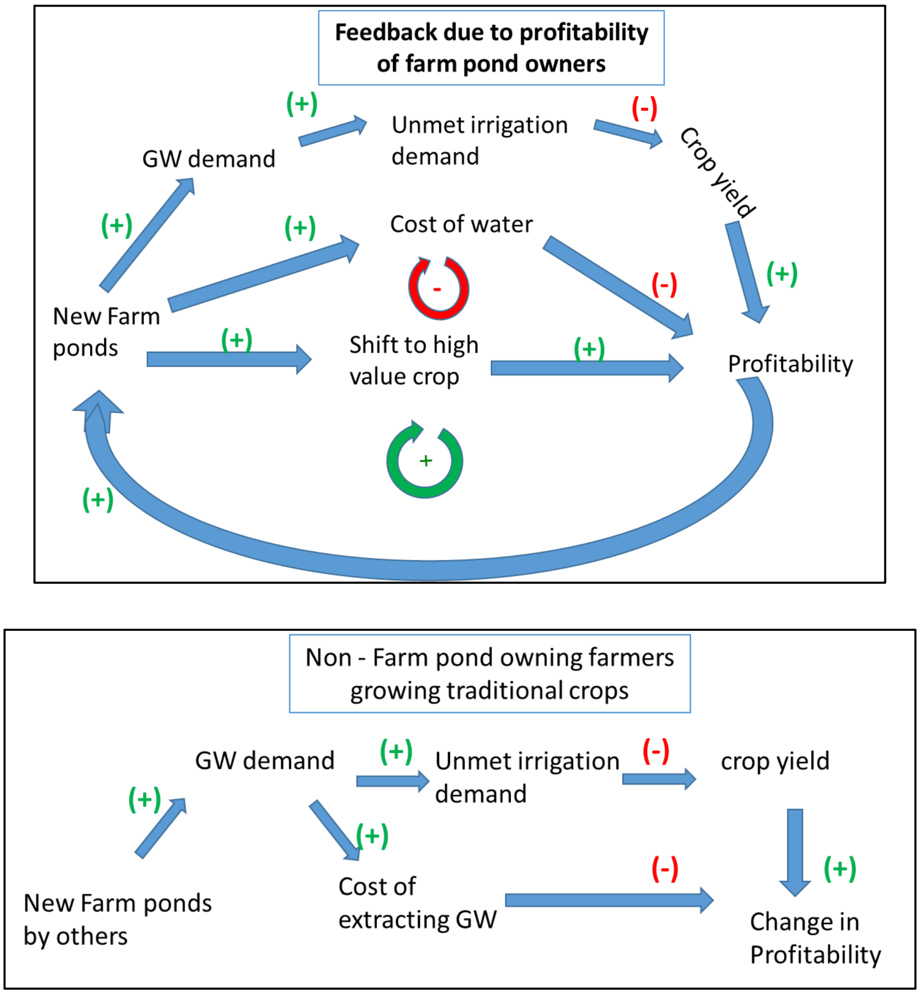
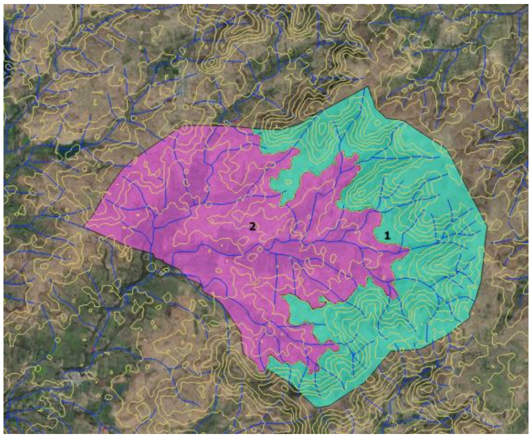


Figure 3: Modelling of economic factors

3. Model set up and calibration

This section discusses the setup of the model and its parameters. The model simulates the hydrological processes of a typical village. However, in order to keep it grounded in reality a specific village is chosen to set up the biophysical attributes. The baseline model is calibrated to ensure that the resulting stocks and flows are consistent with field observation. Ground water behavior varies spatially within a village due to variations in factors such as slope, soil type, aquifer properties etc. For simplification, this model "lumps" the geographical region into two zones each of which is assumed to have uniform properties. These are: a ground water recharge zone and a



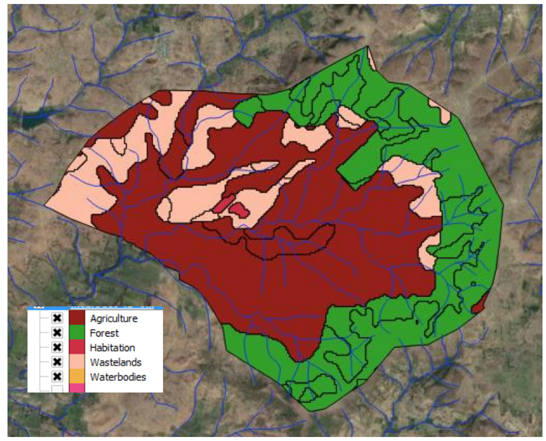


Figure 4: Zone boundary and Land Use Land Cover map of Gondala village

groundwater discharge zone. This is necessary because some regions within a village may be net positive in subsurface flows while others may be net negative. This model allows observation of the impact in each zone.

For setting up the model, biophysical attributes such as geographical geometry, soil properties, cropping patterns etc. are based on attributes of Gondala village of Hingoli district (approximately 19.7299N 76.8951E). The results, however, can be extended to any domain consisting of two zones which are interconnected through surface and ground water flows.

Figure 4 shows the village boundary of Gondala village which also roughly corresponds to a watershed boundary. It receives an average rainfall of 837mm. The two zones in this case are: an upstream zone 1 (480 ha area) and a downstream zone 2 (565 ha area). The land use pattern in Figure 4 shows the larger agricultural land in zone 2 and a more diverse land use (forest, waste land and agriculture) in zone 1. Zone 1 is hilly, and has predominantly poor quality and shallow soil causing high run-off. Downstream zone 2 has better and thicker soil and larger agricultural area. It is more water rich due to stream flows and ground water flows coming in from zone 1 and hence it has higher cropping intensity. From ground water perspective, zone 1 is net loser and zone 2 is net positive due to subsurface flows between them. When the net inflow of subsurface flows in zone 2 exceeds its aquifer capacity, the "excess" ground water is modeled to emerge on the surface as "base flow" in zone 2 and flow out of the watershed.

This paper focuses on creation of farm ponds within zone 2. The effect of zone 1 is considered in the model since it is an important source of stream water and ground water flows into the zone of interest. The same model can easily be applied to Zone 1 as well.

Figure 5 shows the main stocks and flows in the two-zone hydrological model. The auxiliary variables have been hidden in this view in order to keep the view readable. (Note: *Bandhara* may be translated as the stock of water stored in small dams and public reservoirs). The surface run-off and recharge to groundwater are exogenous inputs to the model. They have been computed using a rainfall runoff analysis (Wagner et al 2011). To keep the model simple, stochastic behaviour is not modeled and the rainfall pattern is assumed to be constant every year. Ground water flows between zones is dependent upon the difference of ground water heads in the two zones and is modelled from first principles using Darcy's law (Wang et al. 2016).

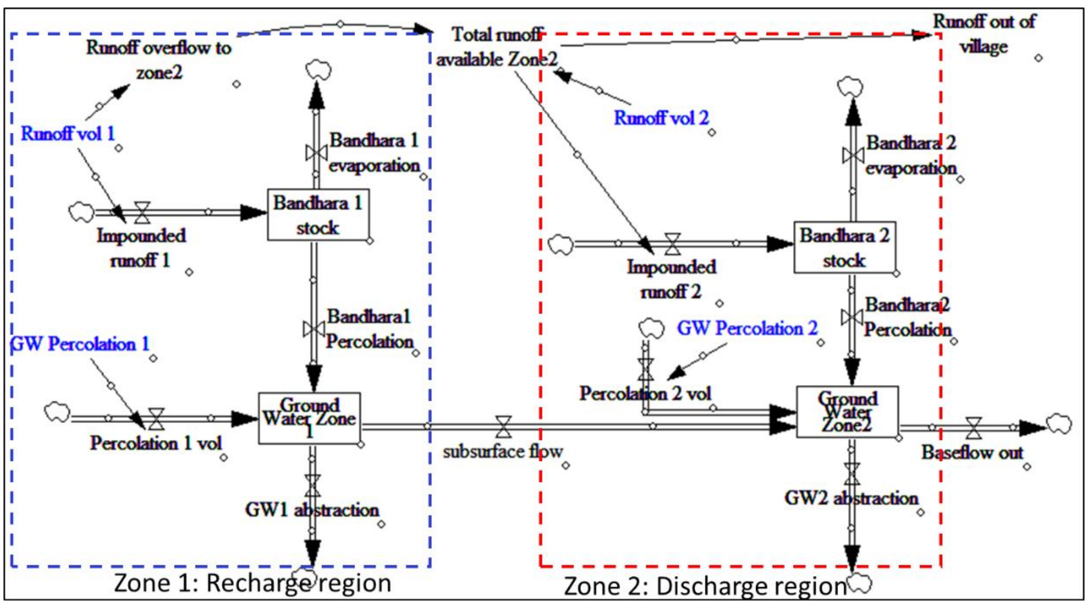


Figure 5: Hydrological Model

Months 0 to 4 make up the rainy/ Kharif season starting from June. The Kharif crop is assumed to get its required water from the rain and there is no groundwater extraction for it. Most villages have some small dams (*bandhara*) in their streams. Depending on the *bandhara* (or dam) capacity, certain amount of run-off is impounded by them from the rainfall runoff. Water from the *bandhara* is gradually lost as evaporation and some percolates down to meet the ground

System Parameters	Zone 1	Zone 2
Area (ha)	481.63	565.15
Ground elevation (m)	510	465
Well depth (m)	7	9
Baseline Rabi sown area (ha)	200	250
Baseline Rabi GW demand (mm of water column)	200	250

Table 1: System Parameters

water table. Throughout the year, there is a sub-surface flow from zone 1 to zone 2. Part of this flow seeps out as baseflow in zone 2 when the net subsurface flow into zone 2 exceeds its aquifer capacity. Months 5 to 9 make the Rabi season during which there is groundwater extraction in each zone to irrigate the Rabi crop. When farm ponds are introduced, ground water is extracted in the months of 1 to 5 and stored until months 9 to 11 for irrigation. Table 1 shows the system parameters that have been used for each zone.

3.1 Baseline calibration

In the baseline case it is assumed that all farmers grow traditional low water use crops and there are no farmponds. The rainfall pattern as well as ground water extraction is assumed to be the same hence the parameters are identical every year. The model is run at a monthly time step for 5 years. (Note: Month 0 to 1 is June, 1-2 is July etc.).

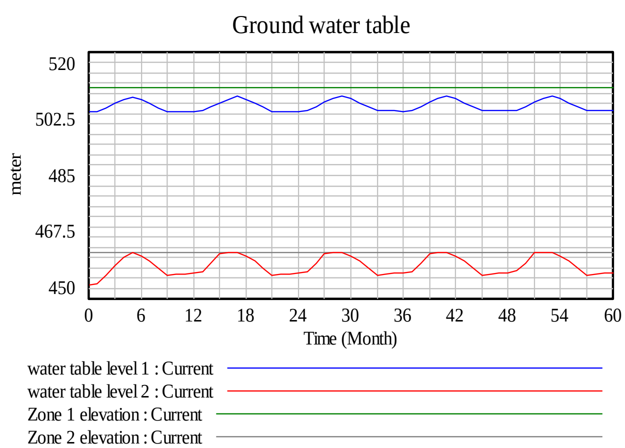


Figure 6a: Ground water table

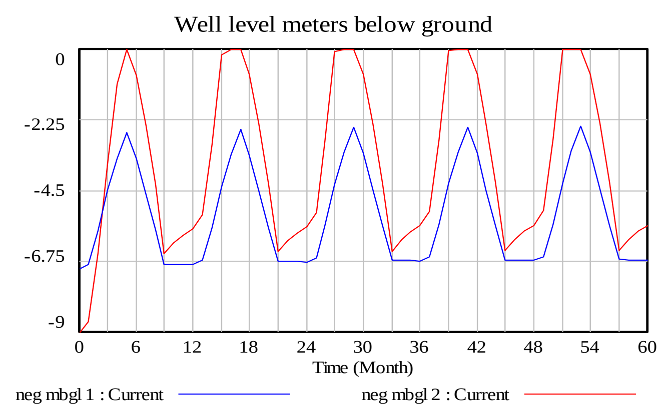


Figure 6b: mbgl levels

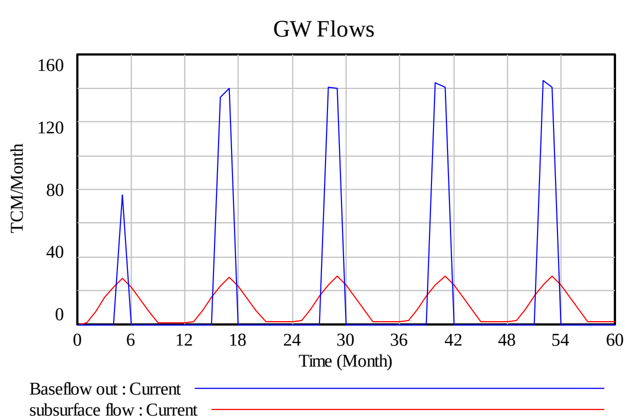


Figure 6c: Ground water Flows

Figure 6a shows the ground level elevation as well as the fluctuating ground water levels (with respect to mean sea level) for each zone. As shown, Zone 1 has a higher elevation (510m) vs. zone 2 (465m). The blue and red graphs show the variation of ground water table in zones 1 and 2 respectively. Figure 6b shows the same ground water level in the form of meters below ground level (mbgl). For example, a value of 0 mbgl implies that the wells are completely full with water. As can be seen by these figures, wells in zone 1 do not fill up to the brim during the rainy season. They have very little water in the summer months, only to meet domestic demand. In contrast, zone 2 wells are full by the month of October. Levels start to go down due to Rabi extraction but since there is no extraction in summer, well levels recover and have sufficient water for domestic use in the summer months. Initial value for ground water stock is chosen as 0 for year 1 and the model stabilizes by year 2.

Figure 6c shows that there is a constant sub surface flow (shown in red) between zone 1 and zone 2, except in summer months when they become very low due to the low zone 1 wells levels. Baseflows (shown in blue) flow in zone 2 until Nov end. The behavior shown by various stocks and flows in the model is consistent with the observations on field.

4. Modeling impact of farm ponds

The previous section modeled the baseline scenario with no farm ponds. From here on, the comparatively water-rich zone 2 is the focus of the model and the impact of introducing farm ponds in this zone in analysed.

4.1 Farm ponds and cropping decisions

The section focuses on modeling the feedback loop related to changes in cropping pattern as shown in Figure 2.

<u>Cropping pattern shift</u>

Four types of cropping practices are modeled:

The baseline cropping pattern is assumed to be one of the following two options:

a) Rainfed Kharif crop + land left fallow in Rabi season

b) Rainfed Kharif crop + traditional Rabi crop (such as green gram or sorghum)

Farmers who build farmponds shift from the baseline cropping pattern to the following types of cropping pattern

c) Rainfed Kharif crop + water intensive Rabi crop (such as onion or tomatoes)

d) Year round orchard such as pomegranate

The shift in cropping pattern has been modeled by considering the following stocks of land: fallow land (no Kharif or Rabi), Kharif only land stock (no Rabi), Traditional Rabi cropping land, land under farm pond irrigated water intensive Rabi crop and land under farm pond irrigated orchards (see Figure 7). The model assumes that 80% of farm ponds are used to irrigate fruit orchards (0.4 ha of fallow land is converted to orchard for every new FP). 10% of remaining farm ponds are used to irrigate Rabi crop on land that was previously used for only rainfed Kharif crop. The remaining 10% of the farm ponds are assumed to be used on existing Rabi area but for a more water intensive Rabi crop. Note that these numbers are consistent with reported observations in villages such as Kadvanchi that have experienced farm pond revolutions (Pawar et al 2012, Ansari 2016).

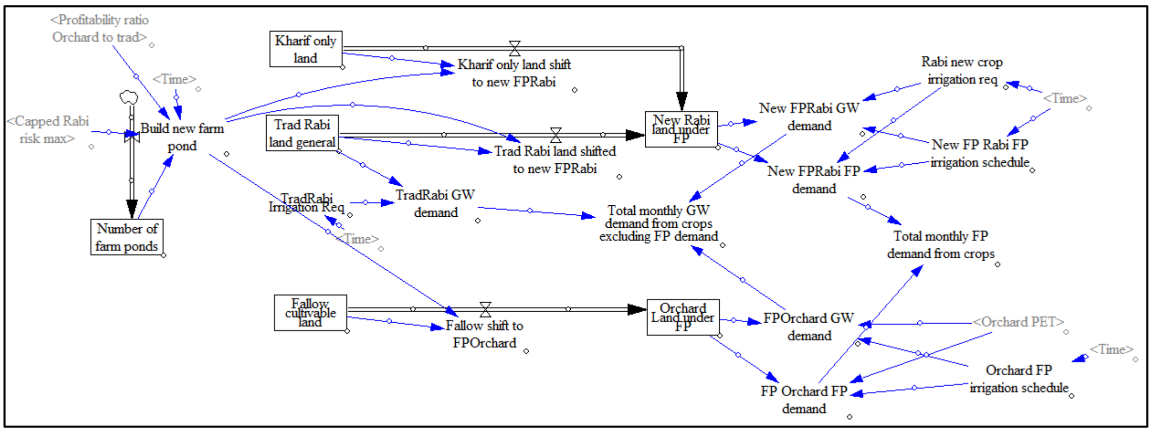


Figure 7: Modelling cropping pattern shift and changing irrigation demand

Change in ground water irrigation demand

Land under each type of cropping has a bearing on irrigation water demand. Traditional Rabi crop water demand is fulfilled purely through groundwater extraction. Water intensive Rabi crops are irrigated through ground water extraction in the initial waterings and the final 3 irrigations are provided through water saved in farm ponds. In case of orchards, farm pond water is used to irrigate in three months of summer while rain water and ground water are used in the remaining months of the year. Monthly water requirement for each type of crop is setup in the model.

Evaporation losses from farm ponds

If a lined farm pond has 2 TCM of water filled by the month of October, this reduces to about 1.5 TCM by mid-February even without any use due to evaporation losses. Hence, if the farm pond is to be used to cultivate vegetables in summer, 133% of required water is to be extracted in the monsoon months to allow for evaporation losses. This inefficiency of farm pond use is incorporated and impacts ground water extraction (see Figure 8).

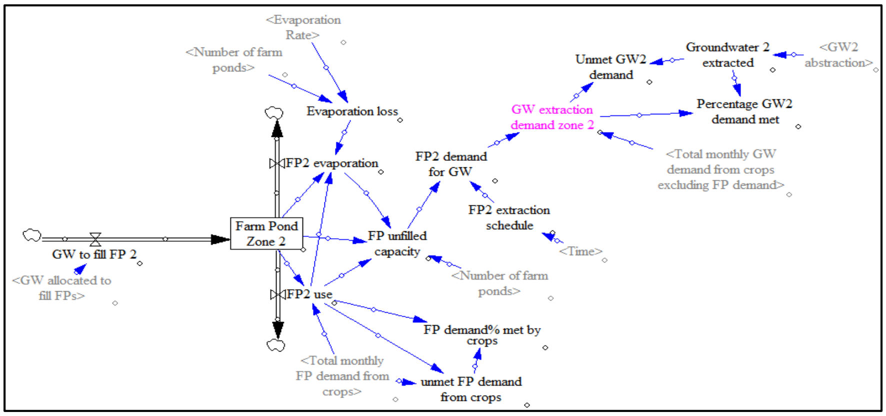


Figure 8: Modelling evaporation losses from farm ponds and computation of groundwater demand

<u>Modeling risk in ground water unavailability</u>

Groundwater risk is modeled as the ratio of net ground water demand to the ground water stock available at any time step. In low risk scenario, demand should be a fraction of the available stock of ground water. But as demand rises and GW stock falls, this ratio starts to increase and the risk of not meeting ones irrigation demand rises. When the ratio exceeds 1, it is certain that irrigation demand will not be met by some farmers. As this ratio increases, more farmers are incentivized to assure water for their farms by investing in farm ponds.

4.2 Farm ponds and economic considerations

Economic considerations are added in this third part of the model. These are in terms of cost of water, cost of cultivation, farm output value and farmer profitability.

<u>Cost of water</u>

Cost of water for farm pond owners: The cost of building farm ponds depends upon the soil profile. For a standard farm pond storing 2 TCM water the annual amortized cost per unit water turns out to be approximately Rs 25 per cubic meter. When government subsidy of Rs 50,000 is availed, it reduces this cost to about Rs 20 per cubic meter.

Cost of groundwater extraction: All farmers who irrigate a Rabi crop (farm pond owners and non-owners) extract ground water for irrigation. Typically, the cost of pumping groundwater is a function of water level depth. The farm pond owners pump the water twice- once from well to the farm pond and second from farm pond to their fields. However, in practice, pumping cost is negligible for farmers in Maharashtra due to state subsidy on agricultural electricity. Hence this cost is ignored. Thus, as farmers invest in new farm ponds, their cost of unit water increases.

Unmet irrigation demand and allocation of ground water

As the irrigation demand increases with new farm ponds and ground water levels fall, a stage is reached when not all demand for water is fulfilled. Ground water is first allocated to fill farm ponds since this extraction occurs during the rainy season. Post rainfall, there is a competition for ground water. It is assumed that farmers who have farm ponds and orchards are the most asset-rich farmers (having stronger pumps and deeper wells) and hence groundwater is allocated to them first. This is followed by farmers with farm ponds growing water intensive Rabi crops. The remaining available groundwater is allocated to the non-farm pond owning farmers who grow traditional crops. This is shown below in Figure 9.

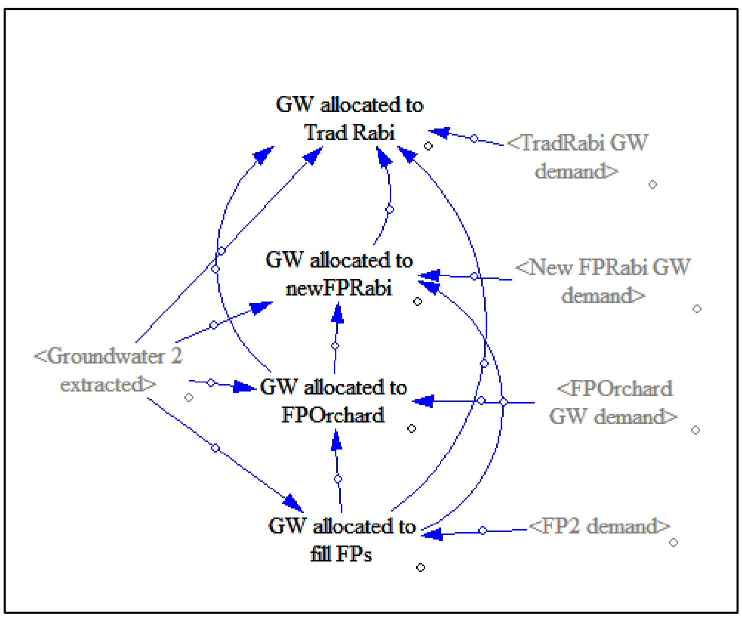


Figure 9: Allocation of groundwater when in stress

Crop yield as a function of irrigation received

Simplified yield curves are used to model crop yield as a function of irrigation received. The basis for these yield curves is surveys conducted in drought affected villages of Nashik district. In case of traditional crops (which tend to be drought-resilient) yield is assumed to change linearly with water applied upto the published yield value for fully irrigated crop (Directorate of Economics and Statistics 2014). For more water intensive Rabi crops yield is assumed to be zero until at least 50% of irrigation is provided after which yield is made to increase linearly upto the published yield value for fully irrigated crop. For orchards such as pomegranate, if the farmer is unable to meet the irrigation demand it is assumed that he will purchase water tankers instead of taking a hit on the yield (as is observed in practice). Based on survey data the cost of tanker water is about Rs 83 per cubic meter. This cost is added to the cost of water to calculate the farmer's profitability as a function of cropping pattern and access to water. The increase in cost of water and the decrease in crop yields, both have a reducing effect on farmer's profitability.

Farm profitability

Each type of cropping practice is assigned a profit function that is computed endogenously in the model. It depends on the following factors: type of crop, area under that cropping practice, cost of cultivation per unit area of the crop, cost of water, crop yields and average market rates per unit production. The cost of cultivation and average market rates are published numbers for the state of Maharashtra (Government of India 2014, (Directorate of Economics and Statistics 2014). Figure 10 shows the profitability modeled for two of the crop choices.

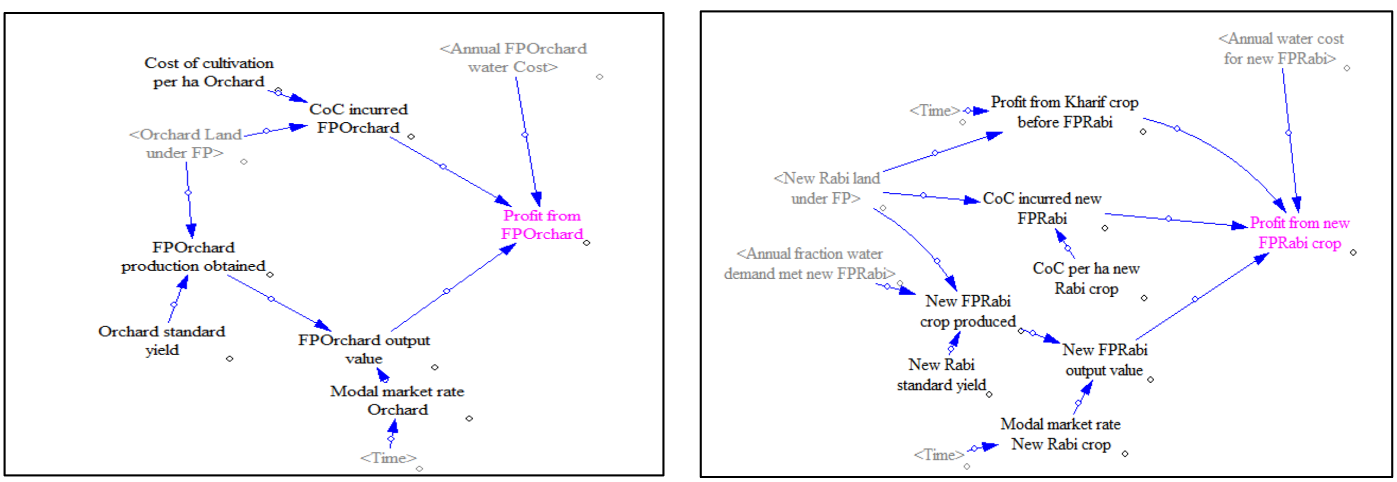


Figure 10: Modelling profitability

Feedback loop for adding new farmponds

New farm ponds created on the basis of two influencing factors a) the relative profitability of farmpond-owning farmers compared to traditional cropping farmers and b) the risk in groundwater availability as described in section 4.1.

It is assumed that there are no farm ponds in year 1 and year 2. In year 3, a government program provides 10 farm ponds to farmers in the village. These 10 farmers change their cropping pattern and shift to higher value water intensive crops. This increases the groundwater demand and impacts the ground water risk factor. It also changes the farm pond owning farmers' profitability. New farm ponds are added when the ratio of profit per unit area of farm pond owning farmers to the profit per unit area of traditional crop farmers is greater than 1. Moreover, if these farmers also face uncertainty in ground water access (groundwater risk is greater than 1) they have additional incentive to build farmponds as long as the first condition holds true.

5. **Model Results and Discussion**

Figures 11 and 12 present the key output of the model. As can be seen, the number of farm ponds grow exponentially before flattening out in year 23 at 284 farm ponds. This is accompanied by a cropping shift by farmers who build new farmponds. As a result, the traditional Rabi cropped area reduces from the initial 250 ha to about 222 ha. Area under orchards rises from 0 to 91 ha and area under water intensive Rabi cropping such as vegetables rises to 57 ha. The GW demand curve shows how demand for ground water increases as new farmponds are built and cropping pattern shifts occur. After year 18, the ground water stock cannot support this large demand and there is unmet irrigation demand. The well levels shown in the well mbgl graph shows the behaviour of the water table. It shows that the well levels fall to greater depth but fill up to brim until year 18 (month 216). Year 18 is also the year when baseflows nearly dry up in the village as shown in the Flows graph. Starting year 19, ground water situation deteriorates rapidly as the water table sinks exponentially. This shows that base flows provide a ground water buffer to the system. When farm ponds are constructed and GW is extracted to fill them, the extraction first reduces the amount of baseflow leaving the zone before impacting the local ground water level.

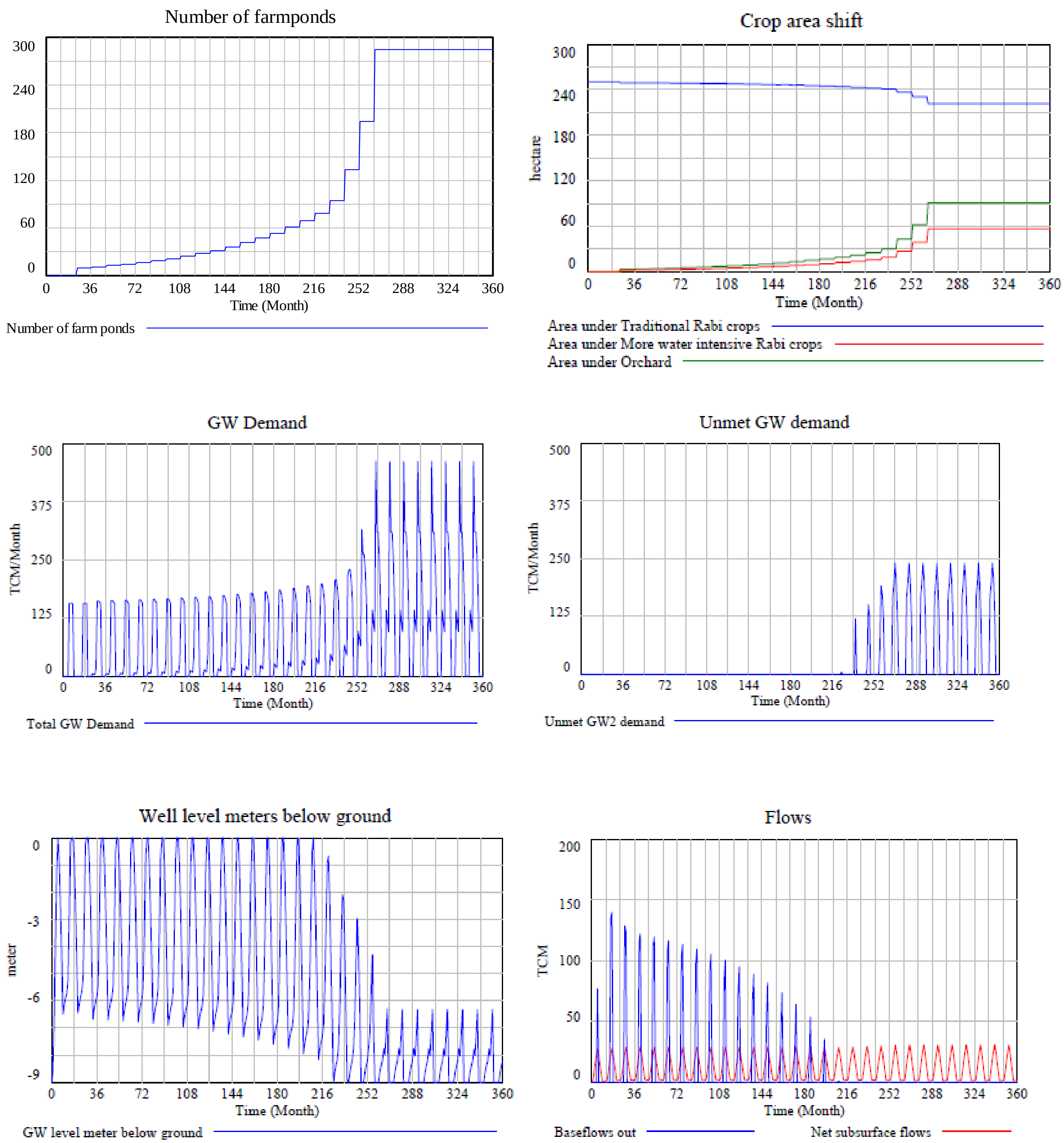


Figure 11: Impact of farm ponds on stocks and flows of the system

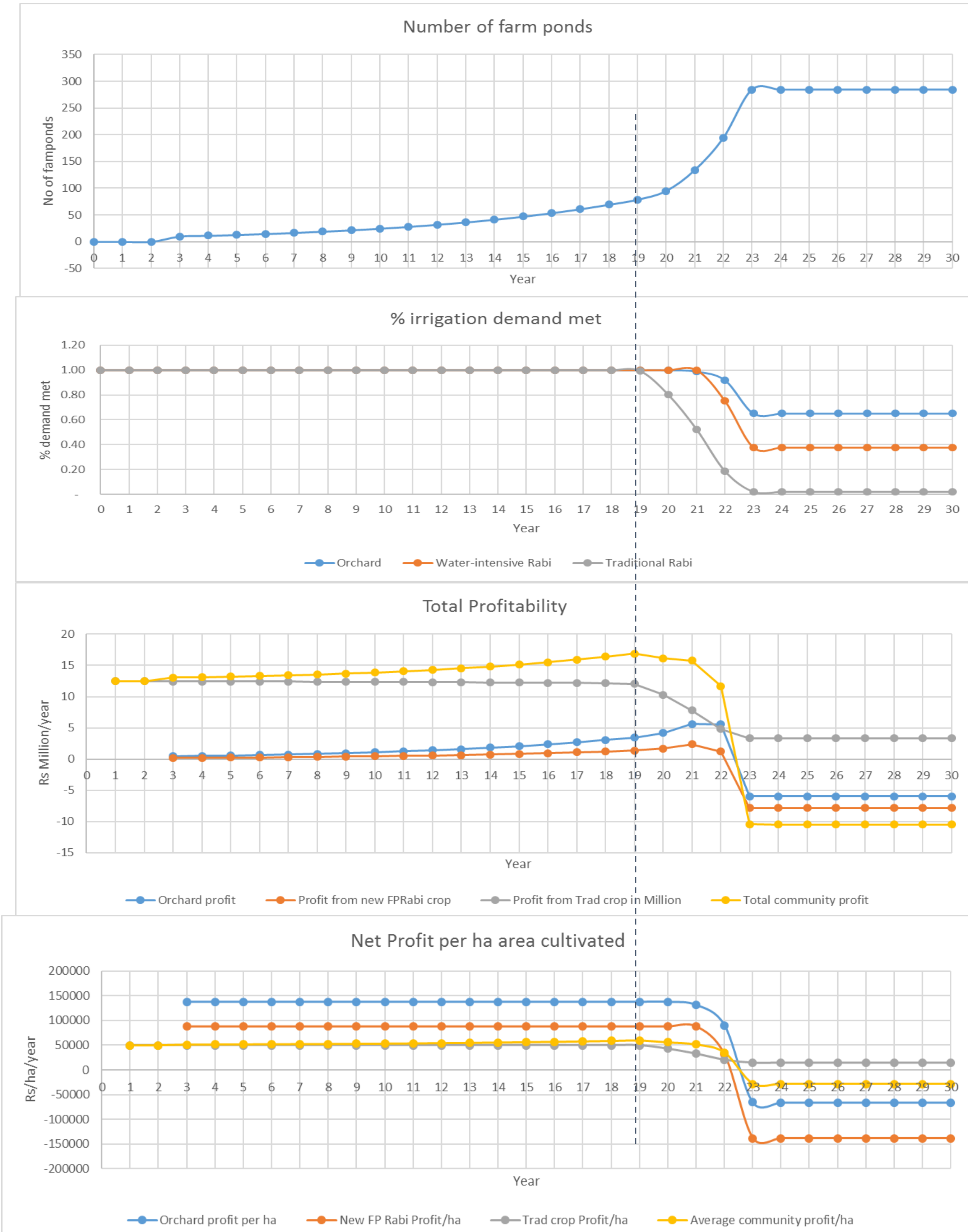


Figure 12: Farm ponds and profitability

5.1 Discussion

The explanation for behaviour shown in Figures 11 and 12 is as follows. Initially there are 10 farm ponds introduced in the village. As these farmers shift to a high value crop, their profitability increases by two to three times. More farmers start to invest in farmponds attracted by this difference in profitability. The initial farmers who convert are the progressive farmers in any village who are economically strong and more willing to take risk. Over the next few years, as farm pond owning farmers continue to be profitable, more and more farmers are incentivized to invest in farm ponds and the momentum starts to rise. As more farm ponds are created, more area comes under water intensive cropping and the demand for ground water continues to rise. The impact of this is seen in lesser and lesser baseflows flowing out of the village post rainy season and also in the well water levels falling to greater depths in summer though recovering during rainy season. These are early signs of groundwater stress.

By this time, some of the shallow wells in the village start to get completely dry in summer. For example, public drinking water wells tend to be shallower than private wells and the landless and asset-poor farmers who depend on public wells start experiencing drinking water stress during summer season. Also, as the competition for groundwater rises and the available stock shrinks, the uncertainty in access to water starts to increase. This doubly incentivizes traditional crop farmers to invest in farm ponds if they can afford to do so: a) because of the increasing uncertainty they are starting to face in ground water access and b) because of the comparatively large profits that farm pond owners are making compared to them.

By year 19, about 79 farmponds have been constructed and the ground water stock is unable to support the irrigation demand and there is unmet irrigation demand. The group that is first affected by this is the traditional Rabi crop growing farmers since they are likely to have less powerful pumps and shallower wells. The unmet irrigation demand impacts their crop yield and reduces their production, thereby reducing their profitability. As this happens, the ratio of the profitability of farm pond owners to that of traditional crop farmers increases even more and investing in farm ponds appears still more attractive.

Over the next two years (year 20 and 21), 39 and 60 more new farm ponds are added. The traditional Rabi farmers see a sudden fall in their ability to access groundwater for irrigation (to about 52% of their demand). By the following year (year 22), the ground water stock has fallen so much that even farm pond owners are unable to meet their irrigation requirement. This leads to a steep fall in their profitability. However, since the traditional farmers are doing significantly worse due to inability to access groundwater that even at this low profit levels orchard farmers are four times as profitable as traditional crop owners. Switching to farm ponds and cultivating horticulture crops appears to be the only way out for traditional farmers and hence even greater number of them rush to get a farm pond adding 90 new farm ponds in year 22 (month 264), thereby taking the total number of farm ponds to 284. This has a devastating impact on the water table. It is able to meet only 65% of orchard water demand, 38% of water intensive Rabi crop demand and practically none of the traditional Rabi crop demand.

This is a severe blow to farm pond owing farmers who make large losses, as horticulture crops are very sensitive to irrigation and even a small shortfall in irrigation results in large losses in yield. Moreover, the high cost of cultivation of this crop makes it risk prone to high losses in case of crop failure. It is interesting to note that the farmers growing traditional crops have no water for irrigation and yet they do not experience a similar loss because of their drought resiliency and low cost of cultivation. At this point, a state of equilibrium is reached as there is no longer any incentive for anyone to invest in any more new farm ponds. However, by the time this happens, every single farmer is worse off compared to the situation from where they began. Economically, each farmer group has lower profitability compared to initial state. In terms of their resources, there is a catastrophic crisis in groundwater. Socially, there is a crisis as well, due to the poor state of pubic wells and drinking water for the asset-poor people and for livestock. What has resulted is the tragedy of the commons. The larger community’s interest is compromised because farm ponds continue to be in individual farmers’ self-interest even when the common pool resource is being exploited.

It is clear that the dynamics between the reinforcing and balancing loops shown in Figures 2 and 3 is such that by the time the balancing loop stops the increase in farm pond, significant damage has already been done. If community action and/or groundwater regulation was possible, an economically and socially desirable state would have been the one attained in year 19 with 79 farm ponds when the overall community profitability is the highest and social costs are not high. It is possible to identify this threshold by the clue that ground water levels and baseflows provide.

When wells no longer fill up to the brim in rainy season and the baseflows dry up, it is a good indicator that the threshold has been reached and no new farm ponds should be constructed

6. Conclusions

There is much interest in farm ponds currently at all levels – farmers, practitioners, policy makers and politicians. However, views on farm ponds are highly polarised and only based on short term experiences. This study offers a system dynamic analysis of farm ponds in terms of their hydrological, economic and social impact. It shows that farm ponds offer great potential for economic prosperity only as long as their number is within a limit that is governed by the hydrology of the area. As shown in the analysis, a good indicator of this limit is the point when wells do not fill up completely during rainy season and baseflows no longer flow in the region post rainfall. If farmers continue to build new farm ponds and grow orchards beyond this limit in an unregulated manner, it will create a vicious circle leading to the tragedy of the commons.

The model shows that in the current policy regime of subsidized electricity and farm ponds, the economics of water would not be sufficient in self-regulating the use ground water and preventing the tragedy of the commons. Regulation of ground water would be required either through policy or community action. Evaluating changes to agricultural subsidies would have other social ramifications, and is out of the scope of this paper.

To conclude, the model establishes that there is a natural limit up to which investments in farm ponds and horticulture can be supported. It is unlikely that a state of equilibrium will be reached at this natural limit without any regulation since economic incentives will continue to drive more farmers to invest in farmponds even as the ground water depletes to dangerous levels. Communication with communities and policy makers using models such as this is crucial to impact policy at the state as well as community level. This work is important to inform programs such as the National Horticulture Mission which currently promote farm ponds for horticulture without any guidelines on where and how many to build.

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