Personal computer as a tool for sustainable development

Vikram Vyas
The Ajit Foundation 396 Vasundhara Colony, Tonk Road
Jaipur 302 018, India
Email: vikram.vyas@me.com

Introduction

In our efforts to evolve towards a global community that lives in harmony with its environment, any tool that can give us some clue as to the impact that our decisions will have on the environment is obviously welcome. Restricting our attention to small rural communities, and to land, water and energy as the resources that we wish to utilize – many questions immediately arise. How should we use these resources so that the future generations too can have access to them? How should we use these, often very limited resources in a manner that the needs of the community are meet reliably? How should these resources be developed without diminishing the richness and the well being of the planet as a whole? In meeting these varied objectives there are many rooms for a conflict, even when the community agrees to the objective and the philosophy of sustainable development.

Consider the case of developing water resources in a small village in a semi-arid region. The community typically has access only to underground water and rainwater stored in open ponds or closed tanks. Our objective would be to meet the water needs of this community adequately and reliably, without exploiting the available resources in a manner that would deny their access to the future generation or cause harm to the environment. This would require answering questions like, to what extent should the community depend on underground water and to what degree should it rely on rainwater harvesting systems? Should it make provisions for recharging ground water? Also, the question of using the water resources in a sustainable manner is related to the use of land and energy sources. Where should we build ponds to store rainwater? What part of the community land be set aside as a catchment area for rainwater harvesting? How to transport water from the sources to the users. Thus, the community is faced with numerous choices and a wrong choice would propagate the error down to the future.

It is here that the ideas of making a mathematical model of the various resources and using the model as a guideline for the future decisions emerge. The idea of using mathematical models for development is of course very old, but its use until now has been restricted to large industrial and developmental projects. So it does not come as a surprise that a modern aircraft is first designed and tested on a computer before even a prototype is build – we would like to know if the aircraft would perform the way we want it to without having to do expensive testing by trial and error. But in the recent decades a new opportunity has emerged which is to use these techniques for small developmental efforts, and this has been possible because the computational power required for modeling, say water resources, is now readily available in form of the ubiquitous personal computers (PCs). My aim in this course is to introduce you to the idea of modeling, and hopefully giving you enough background that you can use the available tools in your own developmental work.

Complementing the modeling is the more familiar use of the PCs, for information storage and retrieval. We will see during the course of this lecture how these two aspects combine together to give a powerful tool for making appropriate decisions for sustainable development.

The outline of the course will be following. In the next section I will introduce the idea of a mathematical model and the related idea of simulation. In the third section I will make these ideas specific by giving an example of model for simulating rainwater-harvesting system. The fourth section will describe how mathematical modeling and information database combine together into an extremely useful tool. The final section will be devoted to an overview of various tools that are available.

Mathematical Models and Computer Simulation

It is an extraordinary fact, which we often take for granted, that all natural phenomenon show a regularity that can be encapsulated into certain “laws” of nature. Further more the natural language in which these laws can be formulated, and their consequences explored, is the language of Mathematics . Perhaps the most familiar example of this is the law of gravitation. It is this law that allows us to predict with incredible accuracy the trajectory of a satellite or a spacecraft. But the processes and phenomenon that will be of interest to us are, in certain sense, more complex. Consider the case of loss of water from a pond due to evaporation, our ability to predict the loss due to evaporation is much more restricted than our ability to predict the trajectory of a spacecraft. It is worthwhile to understand why this is so. It is not that we do not know the laws governing evaporation, our knowledge of these laws is as certain as our knowledge of gravitation, but a law of nature only tells us how things will evolve in the future given the present situation. So to predict the trajectory of a spacecraft we need to know what is its position and velocity to start with, and also the position and velocity of sun, and other planets at that moment. With this information we can predict the future position of the spacecraft. Similarly if we know the temperature of the water, temperature of surrounding air, the atmospheric pressure over the pound, and the wind velocity over the pond, then we can predict the evaporation loss precisely. Taking wind velocity is as an example, what is required is not just the wind velocity at one point but at all points over the pond, since the wind velocity can change rapidly from place to place, therefore a very large amount of initial information is required before we can make an accurate prediction. Obviously such a description and a mathematical model based on its is of no use to the community for determining evaporation losses.

For a mathematical description to be useful for rural development, it has to be based on few parameters that can be easily measured or obtained. Thus, continuing with the example of evaporation loss, what we would like to have is a mathematical model that predicts evaporation loss based only on the average temperature, average pressure, and average wind speed. Such a model in general will be less accurate than the fundamental description of the phenomenon, for we are disregarding the fluctuations in the parameters like wind velocity. Therefore in using the simplified model we would also like to know the validity of the approximations made. To what degree can we trust its predictions? If the accuracy is sufficient then this simplified model becomes a useful tool, allowing us to estimate evaporation losses with known degree of reliability.

Such simplified mathematical descriptions are often called effective or phenomenological models. Their relationship to the fundamental description is many a time incomplete and their validity is based more on comparing their predictions with the actual observations.

For the purpose at hand there is another restriction on a mathematical model to be useful, it should be easily implemented on a PC and the use of the software based on it must not require any specialized knowledge. This requirement is becoming less restrictive as the power of PCs continuously increases.

Closely related to the idea of a mathematical model is the concept of computer simulations. Once we have a mathematical model we can convert it into a set of instructions that can be repeated by a computer as often as we wish. This way we can try different scenarios see their consequences and then choose the most desirable option. Thus a mathematical model of a pond that takes into account the fluctuations in the rainfall, the runoff generated, evaporation losses, and the percolation losses allows us to predict the amount of water that will be available in a given pond during the course of the year without actually having to build the pond! This gives community a tool in helping to decide whether to build a pond or not, and if to build then the model informs it about the size of the pond and the catchment area.

SimTanka – An Example of Modeling Water Resources

To make the ideas of the previous section concrete I will consider a simple and useful example of a mathematical model, and show that how it can be used in meeting our objective of sustainable development. The example I will consider is a mathematical model of rainwater harvesting system with covered storage tanks; the model has been implemented on a PC via software called SimTanka . SimTanka models the performance of a rainwater harvesting systems with covered storage tank. Such systems have been used for more than a millennium in various parts of the world. In western Rajasthan, where their use was very wide spread, they are called Tanka. By performance of a Tanka I mean the ability of a Tanka to meet a given demand. So what SimTanka aims to do is to determine to what extent a given Tanka would meet the demand made on it, and with what degree of reliability. In order to see how SimTanka does this let us follow the sequence of events that takes place when user uses it. As Fig. 1 shows, the user is asked to enter the location where the Tanka is situated or where it is being planed to build. In the above illustrative e.g. the location of Tanka is assumed to be in Bikaner district of Rajasthan.

The rainfall data is an essential information for simulating the performance of the Tanka. As we can see from the representative data of Fig. 2, there are extreme fluctuations in the rainfall. This is a general characteristic of the rainfall pattern in arid and semi-arid regions. These fluctuations in rainfall will obviously reflected in the amount of water collected and stored in the Tanka. If we want to predict the future performance of the Tanka, we cannot use a mean value, say the average monthly rainfalls. That would be misleading. Nor do we have any mathematical model that can predict the future rainfall; the best that we can do is to use the past rainfall record as an indicator of the fluctuations in the future rainfall. It is for this reason that SimTanka needs actual monthly rainfall data for at least last fifteen years, and not just the average monthly rainfall. I will not go into the details of the manner in which SimTanka uses past rainfall data to simulate future probabilities , for our purpose, it is sufficient to know that SimTanka does take into account the various draughts that may occur in the future. Also notice that the user is asked to select the degree of reliability, this is the reliability against the fluctuating rainfall. For e.g. if the user chooses, as in Figure 1, “Extremely Reliable (95%)” then SimTanka will find the minimum catchment area and the smallest possible tank size than can meet he water demands 95% of time, in spite of the fluctuations in the rainfall. Higher reliability, as we will see, comes at the cost of larger catchment area and or bigger tank size.

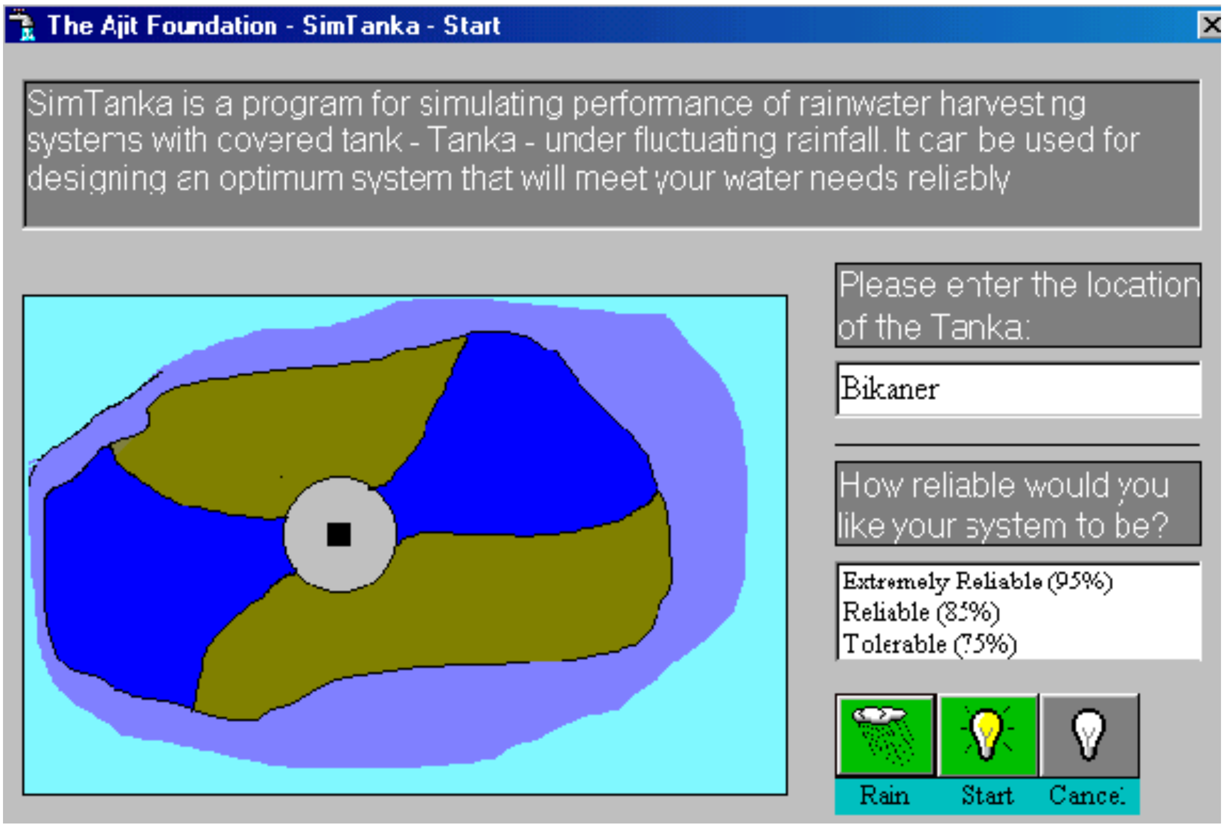

Figure 1. Opening screen shot of SimTanka

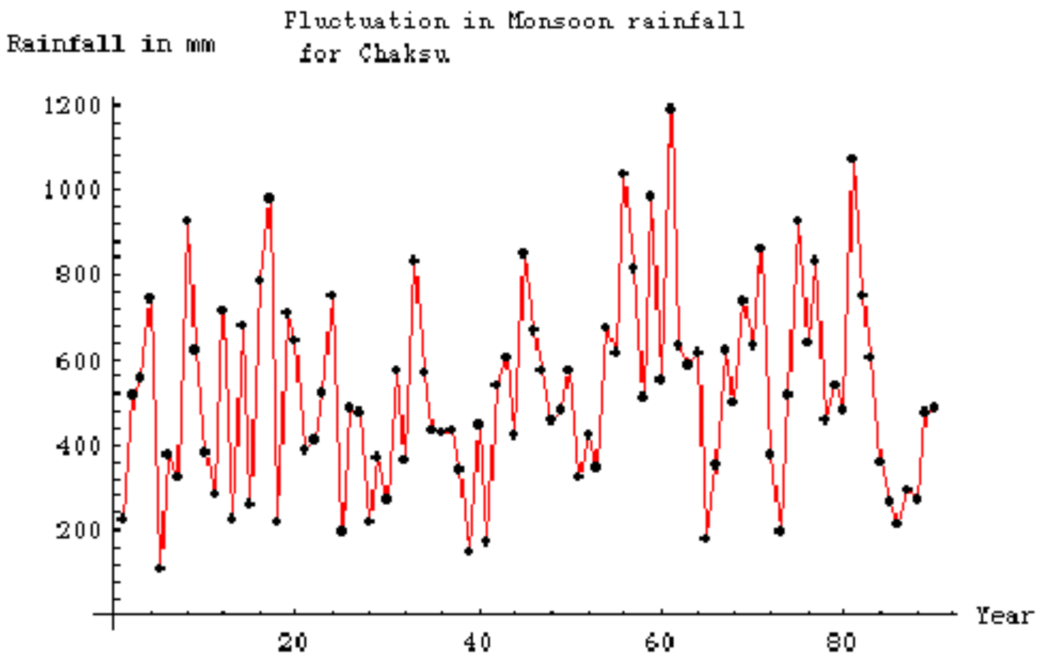

Figure 2. Time-Series of Annual Rainfall Record for Chaksu (Raj.), India.

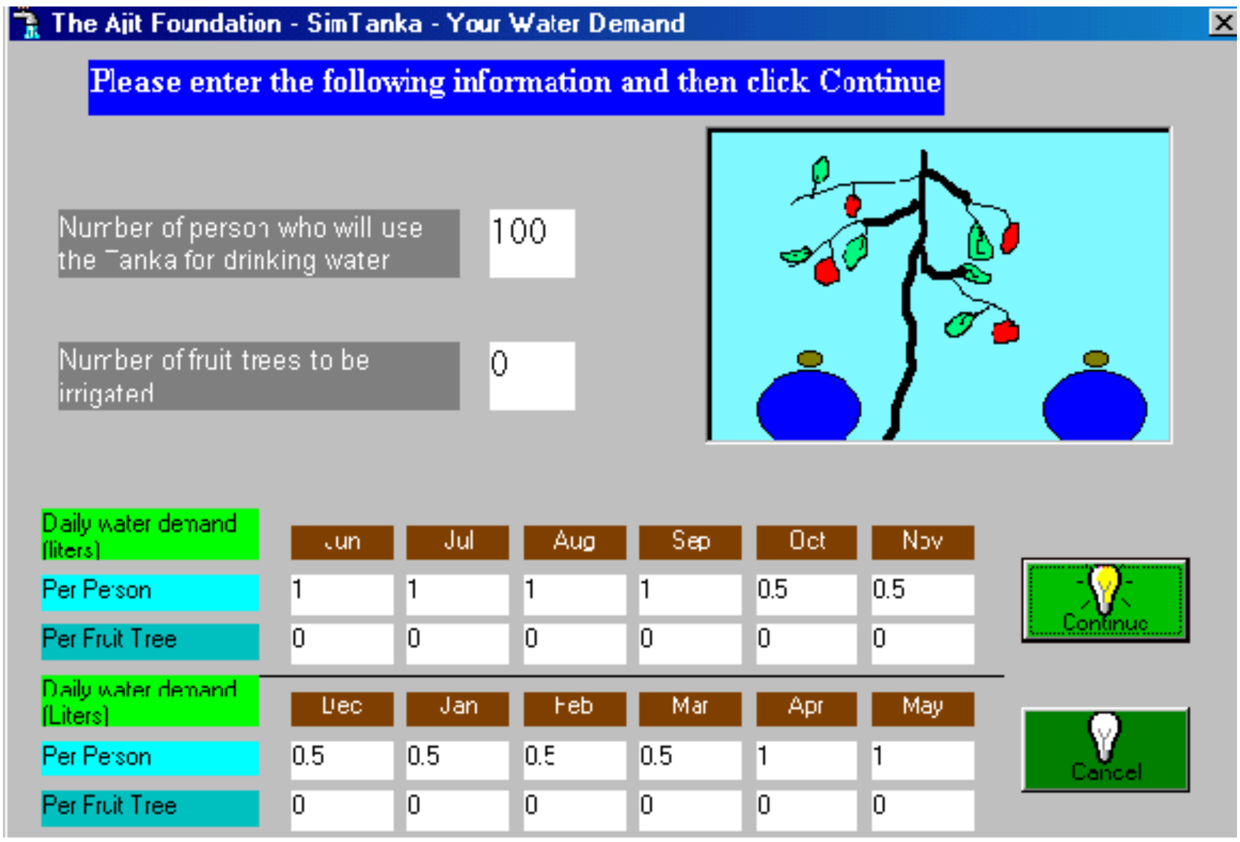

Figure 3. Entering water demand in SimTanka

The user, as shown in the Fig. 3, provides the water demand that will be made on the Tanka. The figures shown in the above screen shot are purely illustrative, reflecting a possible use of Tanka for providing water to schoolchildren. SimTanka does not make any assumptions about the water demands; this is for the community to decide. What it does do is to show the consequences of various demands.

At this stage we have two crucial pieces of information, we know the rainfall record, is likely to face have to face, and we know the water demand. We need one more piece of information before SimTanka can give the parameter for an optimum Tanka. The information we need is the type of catchment area that would collect the rainfall. More precisely we need the “runoff coefficient”, which is nothing but the fraction of the rainfall that goes into the storage, the rest being lost in evaporation and percolation. This parameter tries to encapsulate the complexity of an actual area specific information. We have two choices here, either we can try and model the actual catchment area, taking into account the specific details, and then try and calculate the runoff coefficient, or we take an indicative, conservative value, which approximates the complexity of the catchment area in one single number. In SimTanka the second alternative has been taken, the reason being that the main vulnerability to the reliable functioning of Tanka is the uncertainty in the rainfall and not the uncertainty in the runoff generated from the rainfall. The user provides this single number indirectly by clicking on the surface that best describes the catchment area in a given situation. In Fig. 4 the user has indicated that the catchment area is made of compacted and smooth soil, corresponding to this choice SimTanka take the value of runoff coefficient to be 0.4, that is it assumes that only 40% of the rainfall is collected by the Tanka from such a catchment area, rest is lost in evaporation and percolation. The values of runoff that SimTanka uses are based on empirical studies .

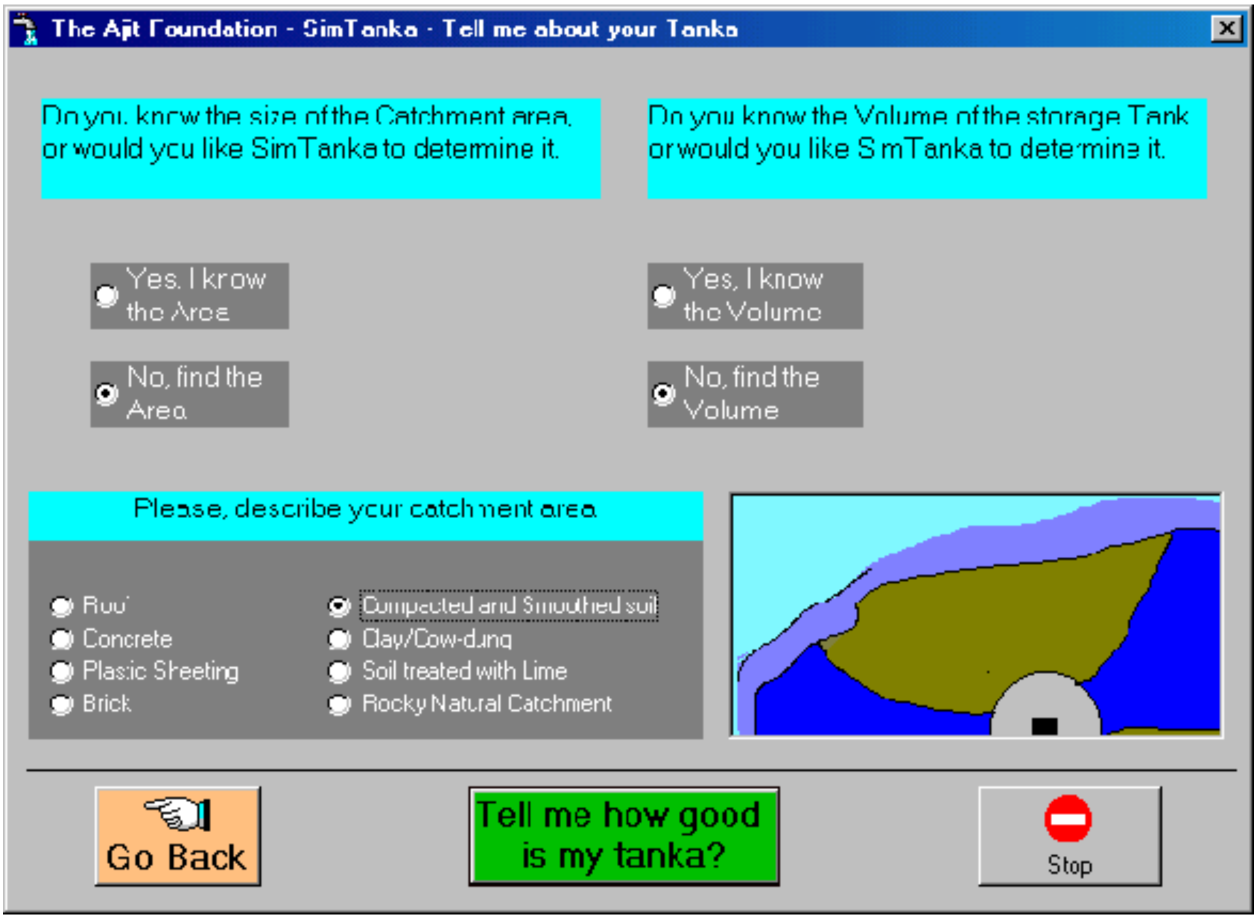

Figure 4. Describing the catchment area in SimTanka

Now we have provided SimTanka with all the information it requires for calculating the size of the catchment area and the size of the storage tank that will meet our demand with 95% reliability. SimTanka tries various combinations of catchment area and tank size. For each such combinations it considers whether the demand will be met or not for each possible rainfall record it has – this way it takes into account all the fluctuations in the rainfall that is encoded in the past rainfall data. The results of these calculations are shown in Fig. 5. For our illustrative example, the result shows that catchment area of 400 square meter and a tank size of 35 cubic meter are required for a Tanka to meet the demand made on it reliably, i.e. 95% of times.

To understand this result better, and also reflecting an actual use of SimTanka, consider the situation when the community cannot provide 400 square meter of land as a catchment area, and say the maximum available catchment area is only 200 square meter (again, I remind you, these are merely illustrative examples). We can simulate this situation too, as shown in Fig. 6. Now SimTanka will try to find the optimum tank size that can meet the demand reliably when the catchment area is constrained to be 200 square meter. The results of these calculations are shown in Fig. 7. We find that with the catchment area being reduced to 200 square meters it is not possible to meet the demand reliably.

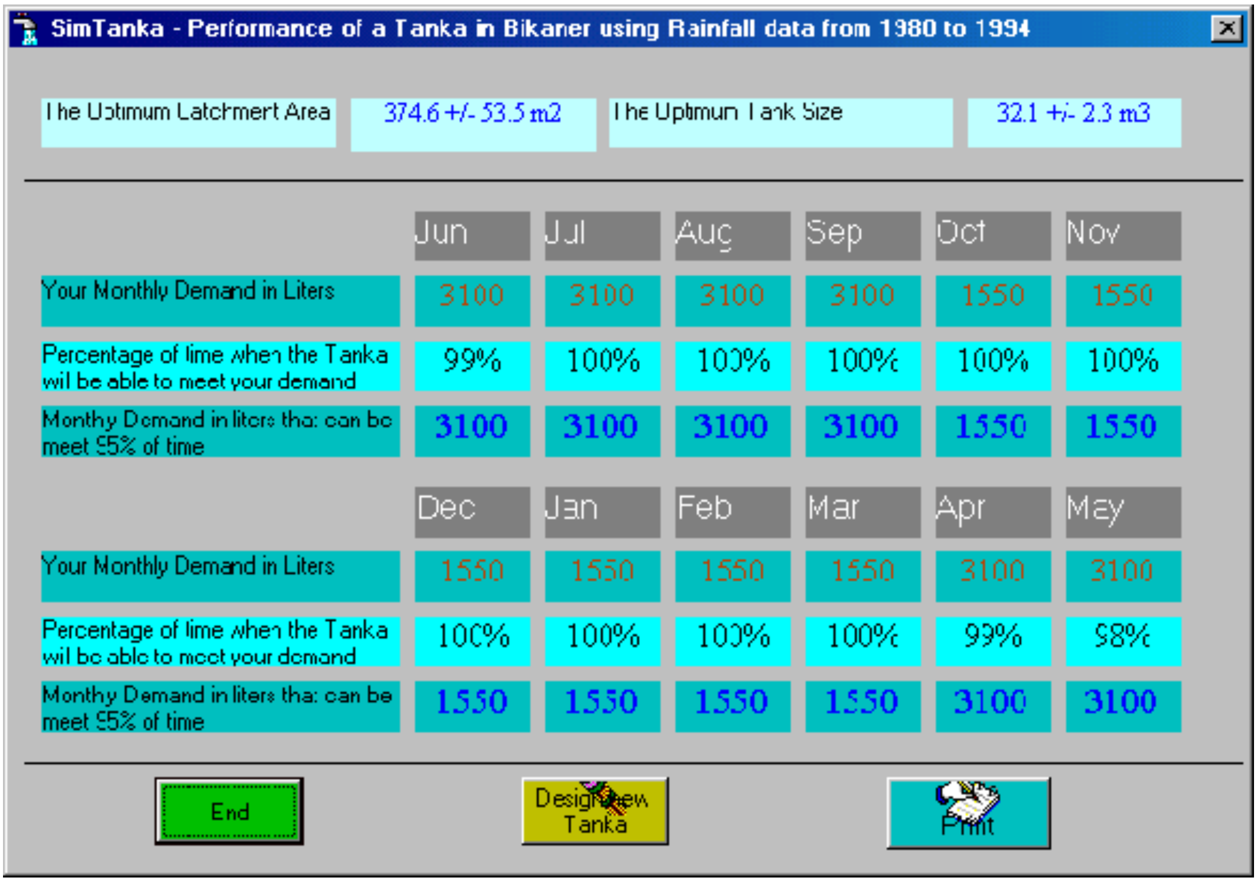

Figure 5. Result of the simulation

Only a smaller fraction of the original demand can be met reliably. For the rest community has to look for an alternate source or increase the catchment area. The decision is now left to the community. Similarly, we could simulate other possibility where the catchment area is freely available but the community can only afford a tank of say 30m3.

Jal-Chitra – Storing and Visualizing Geographical Information

In this section I would like to describe a more familiar use of personal computer, namely to store, retrieve and display information. To illustrate this use I will take as my example software – "Jal-Chitra" that the Ajit Foundation is developing in collaboration with the Social Work and Research Centre, a voluntary organization working in the village of Tilonia (Raj.), India. The aim of Jal-Chitra is to provide an integrated view of all the water sources available to a rural community. One of its uses is to allow the community to prepare for the future eventualities based on the past records. For example, in a given village which has many hand pumps, we may like to know which are the hand pumps that in the past have gone dry during the summer months, and with what likelihood. For this information to be more useful, we would like to display those hand pumps on the village map. This use of Jal-Chitra is shown in Fig. 8 using an imaginary example for illustration. As you can imagine this use of personal computer can often be combined with the previous use, namely developing a mathematical model of given water resource. For example we can try and develop a mathematical model of a hand pump, allowing us to predict amount of water that hand pump can provide as a function of say, rainfall, and nearby recharging structures like percolation ponds. Again, a map is the most appropriate way of displaying results of such simulations.

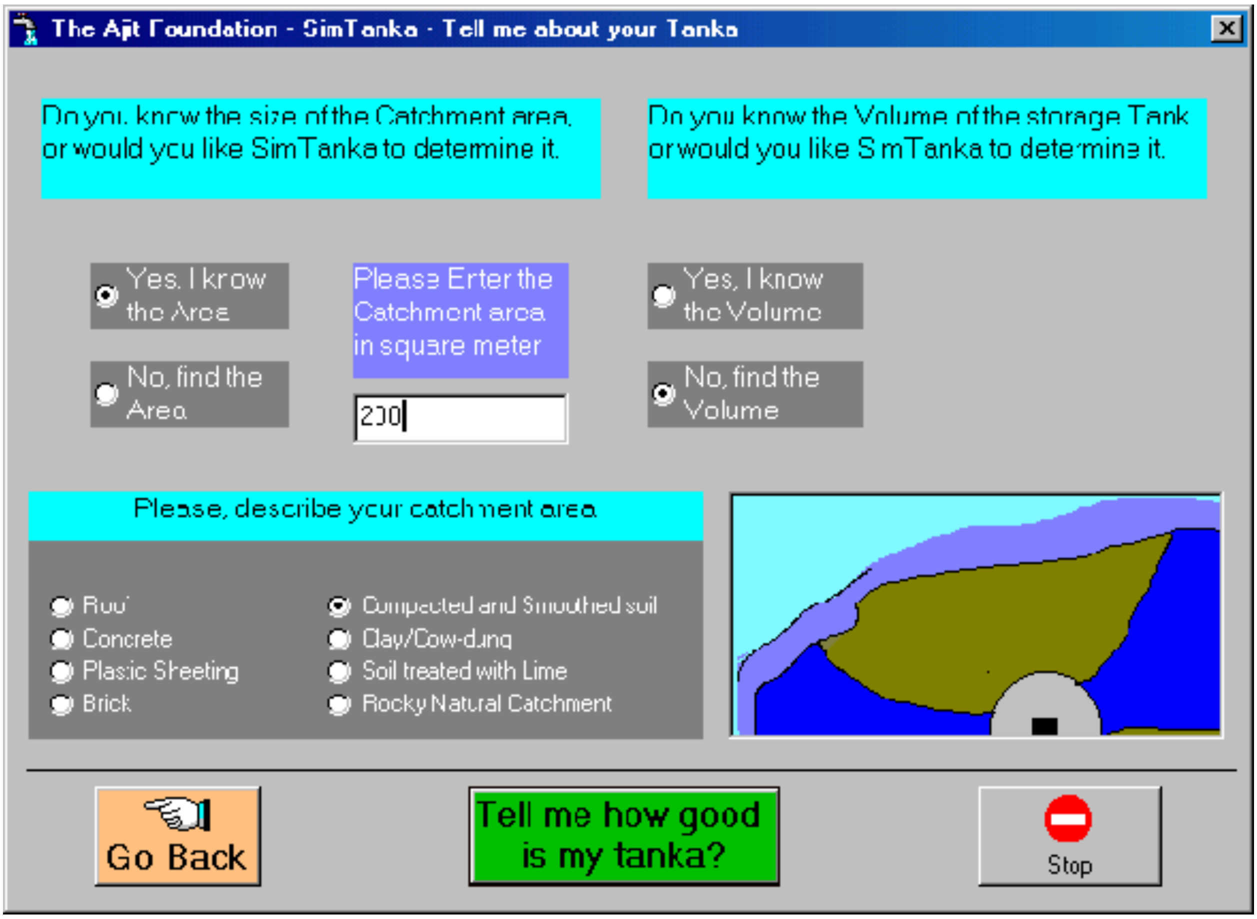

Figure 6 Simulating with a fixed known value of the catchment area

Overview of Available Tools – Internet as a Resource Information

I hope to have convinced you of the use that personal computer can be made in a sustainable utilization of community's resources. The two tools I used for illustration are part of the Ajit Foundation's ongoing work on the use of scientific model for sustainable development. These tools have been made freely available by the Foundation. There are also number of commercial tools that can be used by a voluntary organization. Two familiar examples of such generic tools are spreadsheet program, like Lotus 1-2-3, and a database program like Access. Both these programs can be used for simulating surprisingly large number of situations.

Then there are more specific tools, which are often freely available, and the best place for finding them is the Internet. In particular a most valuable source of water related information is the following electronic mailing list:

water-and-san-applied-research@mailbase.uk. To join this list send an email to mailbase@mailbase.ac.uk with the message:

Join water-and-san-applied-research firstname lastname

where firstname and lastname are your personal names. If you are looking for a specific tool to model a situation sending an inquiry to this mailing list is probably your best bet.

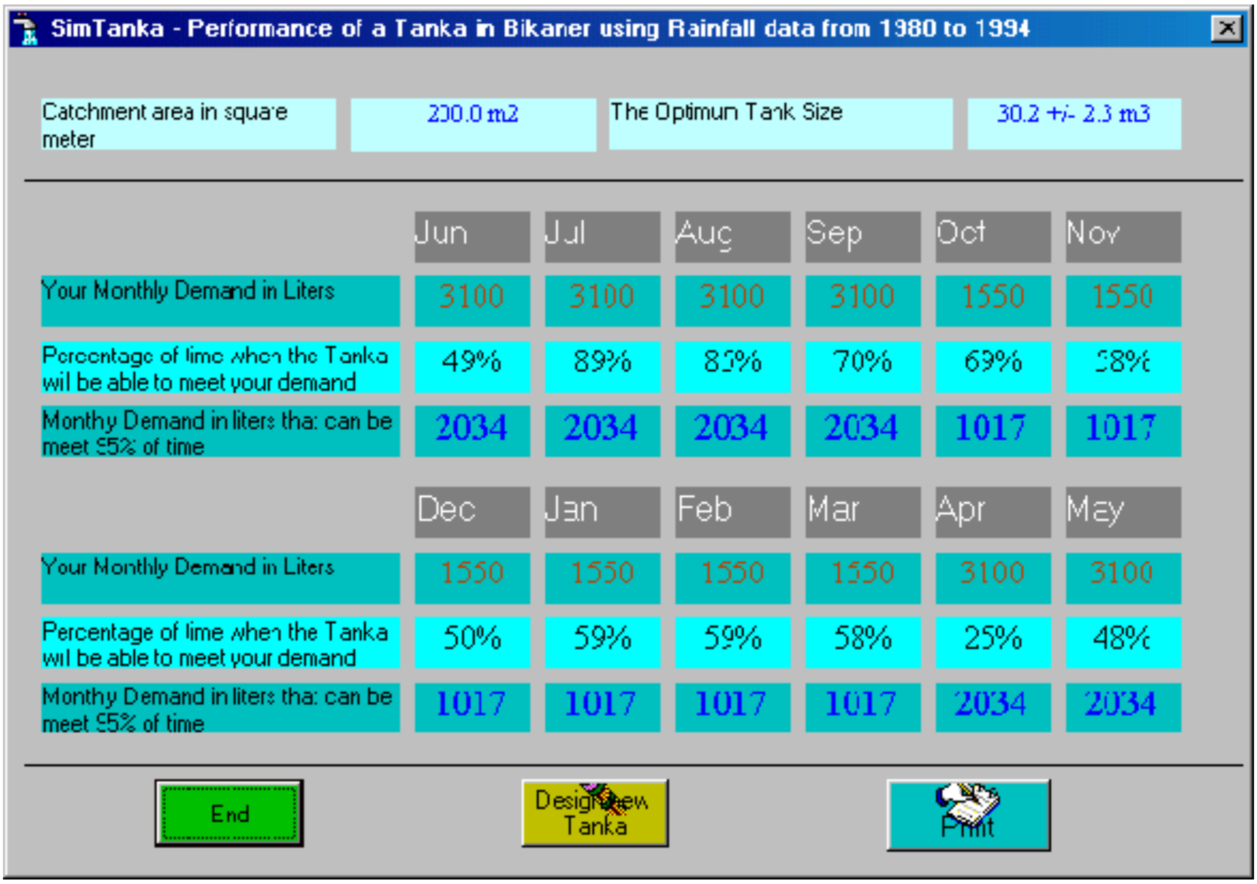

Figure 7 Results of a simulation by SimTanka when the catchment area is fixed

Following is an incomplete list of web sites which contain useful tools for modeling natural resources which was compiled from the responses to my query to the above mentioned mailing list.

- Web site of the International Water and Sanitation Centre: http://www.irc.nl
- The USGS site contains software for hydrological applications:

http://water.usgs.gov/software/

- An expert system for pollution management can be obtained from: http://www-esd.worldbank.org/html/esd/env/themes/themes.htm
- An expert system for sanitation, SANSEX, developed by Thomas Loetscher can be downloaded from: http://daisy.cheque.uq.edu.au/awm/download/sanex/
- SimTanka described in this article can be downloaded from http://www.geocities.com/RainForest/Canopy/4805/

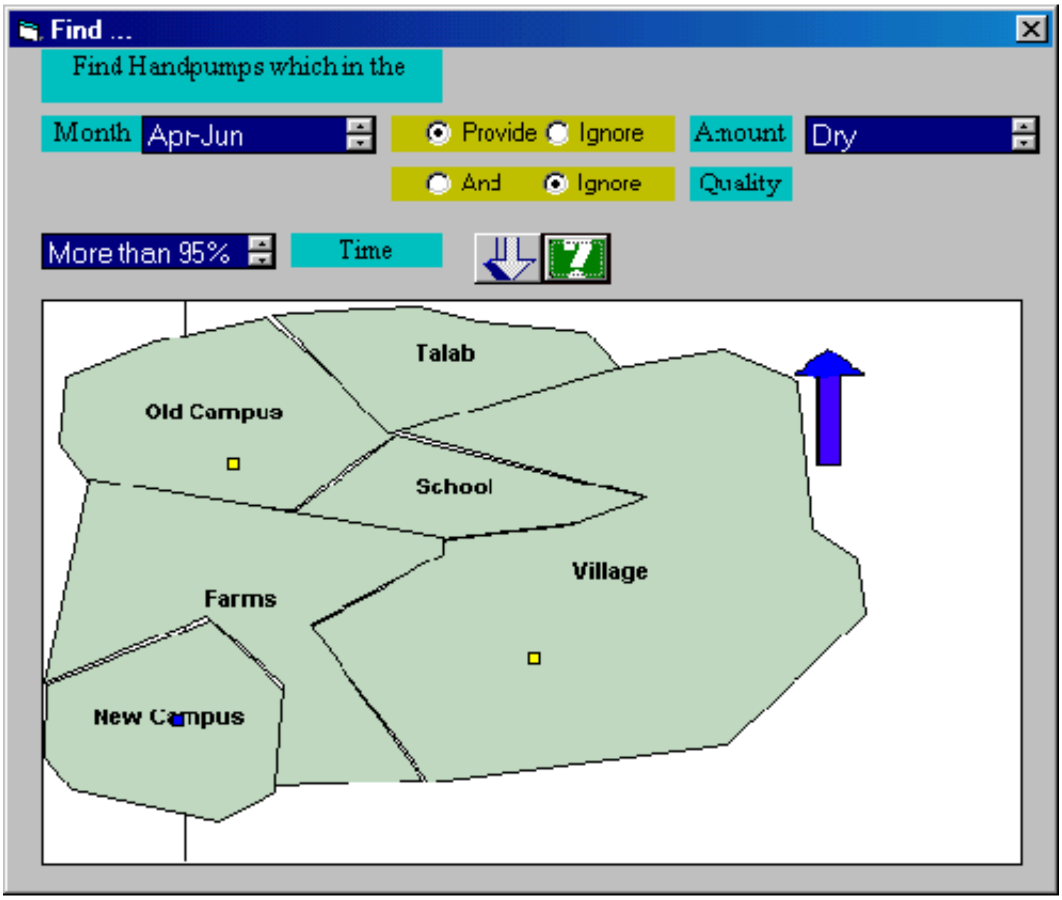

Figure 8 Displaying information on a map of the village

Summary

My main aim in this course was to make you aware of the powerful tool that mathematical modeling is, and how its implementation on a PC gives you a useful way of estimating the consequences of the various decisions one takes regarding the uses of natural resources. I have focused on water, but that just reflects my personal interest and is only illustrative. I have also tried to emphasize that the model that are practical are those which simplify in a crucial manner the actual situation, and thus there results must always been taken as indicative and not predictive – they supplement your and community's own intuition and wisdom, they cannot and are never intended to substitute them. Finally, I encourage you to use email facilities and get in touch with other practitioners with whom you can share your problems and insights and profit from the tools that are available on the Internet.