RESTRUCTURING WATERSHED PROGRAMMES FROM WATER SECURITY PERSPECTIVE

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By

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Dissertation Approval Sheet

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Declaration

I hereby declare that the report entitled "**Restructuring watershed programmes from water security perspective**" submitted by me, for the partial fulfilment of the degree of Master of Technology to CTARA, IITB is a record of the dissertation work carried out by me under the supervision of Prof. Milind Sohoni, CTARA and Prof. T.I. Eldho, Department of Civil Engineering.

I further declare that this written submission represents my ideas in my own words and where other's ideas or words have been included, I have adequately cited and referenced the original sources. I affirm that I have adhered to all principles of academic honesty and integrity and have not misrepresented or falsified any idea/data/fact/source to the best of my knowledge. I understand that any violation of the above will cause for disciplinary action by the Institute and can also evoke penal action from the sources which have not been cited properly.

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ii

Abstract

India is facing a major water crisis according to 12th Five Year plan. Giving access to clean drinking water and access to livelihood water for millions of citizens is going to be a major challenge in the future. Watershed development has been looked at as a major catalyst for transforming low productive rain-fed and arid lands into irrigated and productive lands through various soil and water conservation measures for last few decades. This is reflected in the massive investments in the sector. But over the years, there has been a major shift in the discourse on watershed development from a purely engineering approach to a more participatory approach with deeper concerns for equity, sustainability, livelihood generation etc. During this shift the importance of core planning practices in watershed interventions based on rationality and scientific knowledge seem to have been sidelined which may prove detrimental to overall success of the watershed programmes like IWMP and MGNREGS.

The present study shows that the performance of watershed development programmes depends vastly on the performance of unit watershed interventions like recharging a well through treatment in upper catchment, terracing of a piece of land on slopes etc., the success which depend on a set of good planning practices. These practices include understanding and modeling of needs of the local people, posing their problems correctly, gathering required data from field through observations and surveys or other secondary sources, doing hard-analysis based on the data and needs, designing technically correct plans, predicting fairly accurate outcomes and implementing the plans accordingly.

The present study applies the above set of practices in solving a drinking water problem in a small tribal hamlet, Mograj in Karjat block, Raigad district, Maharashtra through use of groundwater modelling and simulation software (GMS) to show that contour trenches in the upper catchment of the watershed will help in raising the water levels of the *varchi* well.

At a broader level, the evolution of such good practices is essential for creating clear and concrete success indicators in watershed programmes as well as creating well-trained professionals who can work on development projects.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS USED

CRIDA	Central Research Institute for Dryland Agriculture
CSWCRTI	Central Soil and Water Conservation Research and Training Institute
CTARA	Centre for Technology Alternatives for Rural Areas
DDP	Desert Development Programme
DEM	Digital Elevation Model
DPAP	Drought Prone Area Development Programme
DPR	Detailed Project Report
DRDA	District Rural Development Agencies
EGS	Employment Guarantee Scheme
GIS	Geographical Information System
GMS	Groundwater Modelling Software
HADP	Hilly Areas Development Programme
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crop Research Institute for Semi Arid Tropics
ISRO	Indian Space Research Organization
IWDP	Integrated Wastelands Development Programme
IWMP	Integrated Watershed Management Programme
LBSNAA	Lal Bahadur Shastri National Academy of Administration
MERI	Multi Electrod Resistivity Imagine
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MoA	Ministry of Agriculture
MoEF	Ministry of Environment and Forests
MoRD	Ministry of Rural Development
NBSSLUP	National Bureau of Soil Survey and Land Use Planning
NGO	Non Governmental Organization
NIRD	National Institute of Rural Development
NRAA	National Rainfed Areas Authority
NRDWP	National Rural Drinking Water Programme
NRSA	National Remote Sensing Agency
NWDPRA	National Watershed Development Programme for Rainfed Areas
PIA	Project Implementing Agency
PRA	Participatory Rural Appraisal
PRI	Panchayati Raj Institutions
RVP	River Valley Projects
TAO	Taluka Agriculture Office

TCM	Thousand Cubic Meters
TERI	The Energy and Resources Institute
WCDC	Watershed cell cum Data Centre
WDT	Watershed Development Team

Chapter 1 - Background and Motivation

1.1 Water crisis in India

India faces a major water crisis as per 12th Five Year Plan. Drinking water remains to be one of the daunting challenges in the country with millions of citizens not having access to safe and clean drinking water. At the same time, more than hundreds of millions of people living in semi-arid and rain-fed regions of the country do not have access to water for livelihoods and agriculture, due to which these parts remain economically backward. Apart from this, rising demands of rapidly industrialising and urbanising India make the current water scenario more critical. (12th Plan)

Coming to the supply side, problems such as falling water tables, over-reached limits of surface water storage, threats posed by climate change with its impacts on hydrologic cycle, increasing frequency of droughts and floods, groundwater & surface water pollution etc. make the supply side picture look grim as well. Per capita water availability has gone down from 1816 cum per year in 2001 to 1588 cum per year in 2010. With net water availability remaining more or less constant, it is estimated that about half of the demand for water in 2030 will remain unmet. (12th plan)

1.2 Significance of watershed development

For last few decades Indian government has looked at watershed development as a catalyst for transforming low productive rain-fed and arid lands into irrigated and productive lands through various soil and water conservation measures. There have been numerous watershed development programmes in the past for different needs and different areas like Integrated Wastelands Development Programme – IWDP, Desert Development Programme – DDP, Drought Prone Area Development Programme – DPAP, Hilly Areas Development Programme – HADP etc. run by different ministries like Ministry of Agriculture – MoA, Ministry of Environment and Forests – MoEF and Ministry of Rural Development – MoRD, though currently all the watershed programmes have been brought under one umbrella of the Integrated Watershed Management Programme (IWMP) run under Ministry of Rural Development (MoRD). Apart from these watershed programmes, basic watershed approach of conserving natural resources like water and soil are being adopted by other programmes like Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) and National Rural Drinking Water Programme (NRDWP).

With massive investments done already and even more investments planned for the future, the role of watershed development in addressing problems of very large population is going to be significant.

1.3 CTARA – IITB Water Group and past work

The Water Group at Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology, Bombay has been working on various issues related to rural drinking water for past several years. The group is doing work at different levels, like research, implementation, evaluation and monitoring, policy interventions etc. Some of the projects include construction of check-dam in small hamlet in Karjat block of Maharashtra, taluka-level assessment of drinking water schemes in Shahapur taluka of Thane district, study of behaviour of observation wells and analysis of tanker-fed villages in Thane district etc.

A strong need was felt to gain understanding of watersheds and watershed development programmes, with the bigger aim to understand the role of watershed development in the ultimate solution to water problem, especially drinking water problem, in the country.

1.4 From the 1st stage

A study of a watershed intervention by an NGO in a small tribal hamlet of Ikharichapada in Mokhada block of Thane district was done in 2012. The intervention, in this case subsurface bunds, was supposed to solve the local drinking water problem. The aim of the project was to understand the watershed area, aquifer characteristics and groundwater flows with the help of groundwater modelling and simulation software (GMS) and to scientifically verify the impact of the intervention on the drinking water well. The achievements of the study were as follows

- **Familiarity with groundwater flow modelling** – The study of impacts of sub-surface bunds on groundwater flow in the aquifer was done by using groundwater modelling and simulation software (GMS). This required thorough understanding of the groundwater flow physics and also of the finite difference modelling used in MODFLOW (the groundwater equation solver in GMS).

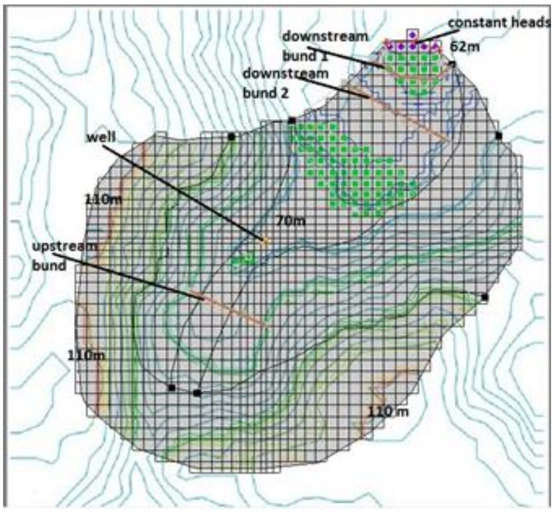


Figure 1-1 – Conceptual model - Ikharichapada

- **Understanding of key attributes required for modelling** – A single-layer conceptual model of the Ikharichapada watershed was developed for simulating the impacts of sub-surface bunds. This helped in formalising the set of attributes / data required for modelling a watershed e.g. terrain data, contour data, soil data, well data, geological data, key observations on the field etc.
- **Simulation results** – The modelling and simulation results showed that the downstream subsurface bunds were more effective than the upstream subsurface bunds in this case. Following graph shows the water levels of drinking water well for different scenarios based on location and number of upstream / downstream subsurface bunds.

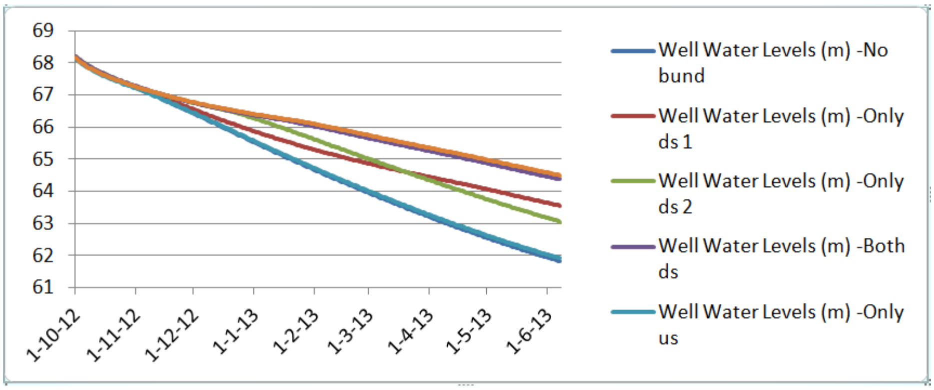


Figure 1-2 – Simulation results - Ikharichapada

The results of the study clearly showed that modelling and simulations can bring more rationality and outcome orientation in watershed planning, monitoring and evaluation (Belsare, 2012).

It was felt that the achievements of the 1st stage should be carried forward to develop an outcome-based planning framework which can be applied in watershed development programmes. This framework would be based on a standard set of practices which include (i) collection of primary and secondary data based on detailed understanding (socio-economic as well as physical) of the local situation (ii) correct representation / modelling of the watershed based on the data collected and (iii) planning and implementation based on scientific analysis.

The present case study focuses on developing such an outcome-based and scientific framework for solving drinking water problem of a typical tribal water-stressed hamlet, Mograj located in Western Ghats rain-fed region (Karjat block, Raigad district) of Maharashtra.

1.5 Objectives of the study

- To understand history and evolution of current discourse in watershed development in India
- To get an overview of the impact of watershed development in India through literature survey of various studies
- To establish the need of and to propose a framework of standard set of practices which can be used in planning of unit watershed interventions like contour trenches
- To use the above framework to help solve drinking water problem of Mograj, a typical tribal hamlet in Western Ghats

Chapter 2 - Discourse on watershed management in India

The philosophy and discourse on watershed development has undergone many changes since the early watershed projects in 1980s. The current discourse on watershed development talks about "watershed plus" approach which has come very far from the early pure engineering approach (Parthasarathy). The present guidelines for watershed development projects (Common Guidelines 2012) focus on a more participatory approach with deeper concern for livelihood issues and overall development of rural economy along with soil and water conservation works (Shah, Mihir). In order to understand this approach in detail, it is necessary to trace back in time and understand the evolution of philosophy behind watershed programmes in India.

2.1 History of watershed management programmes in India

2.1.1 Early pure-engineering approach

Though the concept of watershed approach came into being during late 80s, work on soil and water conservation had begun early in 1960s. The first large-scale soil conservation work was launched in 1962-63, called as Soil Conservation Works in the Catchments of River Valley Projects (RVP). This was a purely technical intervention and was specifically introduced for checking siltation in reservoirs (Joshi, et. al, 2004).

The first area development programme, the Drought Prone Areas Development programme (DPAP), which was later implemented exclusively on watershed-basis, was launched in 1973-74 by Central Government in many parts of the country following the severe drought of 1972. This programme was specifically launched to tackle special problems faced by fragile areas which were constantly affected by drought conditions. At the same time, in Maharashtra, a major step of including drought-proofing works like construction of water harvesting structures, nala bunds etc was taken up on a large scale through Employment Guarantee Scheme (EGS) (Common guidelines 2008).

During the same time, research projects were also taken up by institutes like Central Soil and Water Conservation Research and Training Institute (CSWCRTI) and Central Research Institute for Dryland Agriculture (CRIDA) to validate soil and water conservation technologies and demonstrate the benefits of watershed activities to farming community. In 1980s, Indian Council of Agricultural Research (ICAR) launched 47 model research watersheds on the same lines (Joshi, et. al, 2004).

This was the prime era when the technical discourse on watershed development like new watershed structures, their specifications and design etc. was developed.

Some new programmes like Desert Development Programme (DDP), National Watershed Development Programme for Rainfed Areas (NWDPRA) and Integrated Wasteland Development Programme (IWDP) were also launched during late 80s (Guidelines 2008).

2.1.2 Transformation phase: Watershed as a social organization problem

A watershed is a geo-hydrological unit that drains to a common point. This unit becomes a perfect one for technical works to conserve soil and water and maximise surface and ground water for increasing crop production. But during late 1980s, it was realised that watershed is also an area with administrative and property boundaries. Also, watershed interventions are location specific, meaning that the works done in upper reaches fetch benefits in the lower reaches in most of the cases. Thus it was realised that success of technical interventions depend vastly on, and can even prove detrimental to, socioeconomic relationships among people in a watershed. This was the first major paradigm shift in watershed development which shifted the focus away from pure engineering approach towards systems-based and integrated approach (Kerr, 2002).

During this phase, first instances of people-centred watershed management were seen through the success stories of Vilasrao Salunkhe (Pani Panchayat, Maharashtra) followed by Ralegan Siddhi (Maharashtra), Adgaon (Maharashtra) and Sukhomajri (Haryana). Though these success stories were not seriously considered initially, slowly they started gaining popularity. This was the time when many NGOs started making an entry in watershed development and management activities apart from government and research institutes. Some international funded projects like Indo-German Watershed Development Programme and pilot projects funded by the World Bank were also initiated (Kerr, 2002).

2.1.3 Participatory approach

In 1993, a study was carried out by a technical committee constituted under chairmanship of Prof. Hanumantha Rao for assessment of watershed programmes under DDP and DPAP which were then fully run on watershed basis. The study concluded that, except in few places, in most of the programmes-areas, progress was dismal. The major reasons mentioned by the report were lack of involvement of local people, lack of coordination between different departments and lack of guidelines and norms for implementation of these projects (Rao, H, 1993).

As a result, a common set of operational guidelines evolved for watershed programmes in India. The guidelines brought all the area development programmes like DPAP, DDP and IWDP under one common umbrella of this new ‘watershed-approach’ (Joy, 2004) and gave more focus on the role of voluntary organizations and PRIs for more involvement of local people in preparation of plans and implementing projects. The guidelines also brought in watershed development teams as a platform for people’s participation in planning and gave more stress on capacity building of the people in watershed works.

All the DDP, DPAP, IWDP etc. projects taken up during 1994 to 2001 under different ministries followed these new guidelines, termed as watershed development guidelines of 1994. Around 1999-2000, there were many impact assessment studies done by experts such as Prof. H Rao himself etc. These studies concluded that, although the philosophy was right, positive impact was not seen universally because of complications in the implementation and institutional setups (Rao, H 2000). The guidelines were thus revised in 2001 and then again modified in 2003 by MoRD. The new guidelines gave more powers to PRIs for effective and smooth implementation of projects. These guidelines were called Hariyali guidelines of 2003.

As per the guidelines, the projects were implemented by Gram Panchayats at field level under guidance of Project Implementing Agencies (PIAs). PIAs can be NGOs or government departments. The concept of Watershed Development Team (WDT) was strengthened and was made of multi-disciplinary experts like (Civil Engineering, Animal Science, Agricultural Science etc.). The plans would be approved by new government body, District Rural Development Agencies (DRDA) constituted at district level (Hariyali guidelines, 2003).

In 2006, after a series of evaluation studies conducted by ICAR, ICRISAT, NRSA etc. which concluded that though there were few sporadic success stories, the overall impact of the projects undertaken under Hariyali Guidelines was inadequate. A committee was set up under Dr. Parthasarathy in 2006, which studied the impacts of projects under Hariyali guidelines in detail and led to new guidelines for watershed development projects in 2008. As a result of these guidelines, the powers given to PRIs was taken back and given to PIAs (Parthasarathy, Hariyali to Neeranchal).

A separate entity, National Rain-fed Areas Authority (NRAA), was set up in order to give main stress on economic and ecological empowerment of rain-fed areas, which were left ignored for many years according to Parthasarathy report. All the new projects after 2008 were to be taken up under Integrated Watershed Management Programme (IWMP) under

DoLR. The incomplete projects under other programmes like DDP, DPAP and IWDP were to be converted to IWMP after 2008 (Guidelines 2008).

The guidelines brought in the concept of three phase watershed project – (i) preparatory phase consisting of entry-point activities (for establishing credibility of Watershed Development Team and building rapport with the village community), (ii) watershed works phase for implementation of watershed interventions and (iii) withdrawal phase (for creating proper environment for operation and maintenance of assets and creating sustainable livelihood opportunities) (Parthasarathy).

The guidelines of 2008 were again revised in 2012, after a comprehensive review carried out by Mihir Shah Committee set up under MoRD. It was found that there were number of practical impediments of putting new paradigm set up by 2008 guidelines into practice. Thus, the guidelines were revised in order to demarcate roles of various institutions and to smoothen the implementation process with new innovative changes (Shah, Mihir, 2012).

These new guidelines bring in new institutions like Watershed Cell cum Data Centre (WCDC) at district level to bring professional technical and social support to PIAs with specialists in agriculture / water management, social mobilization, management and accounts etc. Other institutions like National Level Support Organizations (NLSOs) and State Level Support Organizations (SLSOs) are also created for training and support of WCDCs and PIAs (Shah, Mihir, 2012).

Apart from institutional changes, the guidelines give more stress on solving drinking water problem through watershed programmes and additional stress on economic improvement of rain-fed areas along with increase in cost norm per hectare from Rs. 12000 to Rs. 15000, with increase in special norms for hilly areas from Rs. 15000 to Rs. 18000 (Shah, Mihir, 2012).

The following table shows how the discourse in watershed development has been shaped in past 3 decades.

Table 1 - Evolution of watershed development in India

Timeline	**1980s**	**1990s**	**2003 – 2008**	**2008 – 2013**
Policy shifts	Departmental or Research projects	Hanumantha Rao Committee Guidelines	Hariyali Guidelines	Common Guidelines of 2008, 2012
Interventions (Objectives)	Soil & Water Conservation	Boost in agricultural incomes through increase in productivity, increase in cultivated land etc.		Holistic development of rural economy, creating sustainable livelihoods

Strategy	Top down / departmental	Public participation, capacity building	3 phase approach – Entry Point Activities, Watershed works, Withdrawal Strategies
Important players	Government, Research institutes	NGOs, PRI institutions	NGOs

2.2 Current scenario of watershed development in India

Since 2009-10 (as on 31st March 2012), 5830 projects, covering an area of 27.815 Mha have been sanctioned all over India under IWMP. Maharashtra, Rajasthan, Andhra Pradesh and Gujarat cover around half of the area (13.1 Mha) sanctioned. The central funds released for these projects are around Rs. 6000 crores. In the year 2012-13 itself, 1330 new IWMP projects have been sanctioned to cover additional area of 5 Mha with outlay of Rs. 5400 crores (DoLR, Annual Budget 2011-12).

Since 1995-96, total of 50,892 projects have been taken up under different watershed programmes like DDP, DPAP, IWDP and IWMP covering an area of 60.13 Mha and expenditure of around Rs. 24,000 crores. All the incomplete projects under DDP, DPAP and IWDP were continued under IWMP after 2008-09 (DoLR, Annual Budget 2011-12).

It is clear from the increments in the cost norm per hectare of the watershed projects (Rs. 4000 per ha in 1994 to Rs. 15000 per ha in 2012, with additional Rs. 3000 per ha for hilly areas) that the investments in watershed programmes will keep on rising. Watershed development is increasingly gaining attention as a major approach to tackle the problems of economically and ecologically disadvantaged regions of the country (twelfth plan). In light of this, it becomes very important to see what impact and success these watershed programmes have brought over these years and to check whether these projects will prove beneficial in achieving the targets set by the guidelines of 2008.

2.3 Impact assessment of watershed programmes since 1995-96

To assess the impacts of any watershed programme is not a trivial matter. Firstly, the impacts of any watershed project cannot be seen immediately. For example, ecological impacts like reduction in runoff, increase in groundwater levels, increase in vegetative cover etc. or even socio-economic impacts like increase in agricultural incomes, increase in net area sown etc. generally take few years, called gestation period, to realise.

Secondly, the choice of indicators for assessing any watershed project is not straight-forward. Till the point watershed development was seen as an engineering and technical problem, the indicators used to be simple i.e. mainly confined to impact on land and water. But as the watershed problem was started to be seen as a social problem, various other indicators came into picture e.g. impact on livelihoods, impact on agricultural incomes, impact on socio-economic status, impact on disadvantaged sections of the village etc (Joy, 2004).

Thirdly, most of the indicators for assessing watershed projects are not easily verifiable. E.g. increase in availability of fodder / fuel wood, reduction in soil or water runoff, equity in distributing benefits etc. To seriously verify these indicators, a robust and scientific monitoring and evaluation framework is required. Such framework failed to evolve along with the watershed discourse. Thus, there has always been a lack of standard sets of scientific practices for assessing impacts of watersheds. This has given rise to dependence on perception and opinion and some simplistic field observations for evaluating watershed projects (Kerr, 2000).

There have been many assessment studies and reports on watershed programmes since early 1990s. The studies have been carried out by different groups with different perspectives and objectives using different methodologies (Joy, 2004). Technical committees set up under different ministries of government have often evaluated the projects and recommended changes in the watershed approach which has led to evolution of watershed guidelines over the years. Apart from technical committees, studies have been done by academicians, experts, NGOs, international funding agencies and government research institutes (i.e. sponsored by government). Some studies have focused on particular case studies while some have done broad performance evaluations.

Some studies, like Hanumantha Rao, 2000, Mid-term appraisal of the Ninth plan, GOI 2001, Farrington et. al. (1997) have reported that watershed development programmes have been successful in increasing cropping intensity, reducing rainwater runoff, increasing irrigated area, improving drinking water supply etc. The meta-analysis study comprising of evaluation of 310 watersheds done by Joshi et. al. (2000) reported increase in employment generation opportunities along with increase in irrigated area and cropping intensity.

Other meta-analysis studies carried out by TERI, LBSNAA and ICRISAT sponsored by DoLR also reported success of watershed programmes in different parts of the country, with most of the projects doing good at increasing irrigated area by reducing area under degradation, increasing productivity, increasing groundwater tables, bringing in employment opportunities for poor people etc.

On the contrary, there have been few studies by Kerr (2000), Joy (2004), Palisami (2002) etc. who have observed that only few watersheds where participation was good have done better, and the overall impact of the watershed programme was limited. They also reported that people's participation along with sound technical inputs was the key to successful watershed programmes.

Apart from these studies there have been numerous project reports cum case studies and success stories like success stories like Hiware Bazar, Kothapally etc. generated by NGOs and implementing agencies themselves.

In most of the studies, physical interventions like water harvesting structures or bunds, terracing etc. which form the core of any watershed project are studied cursorily. Important considerations like the locations and design of these interventions are ignored while assessment and the assumptions about the success and impact of these interventions are taken for granted. This has resulted into poor reporting and analysis of physical interventions and their impacts on watershed hydrology (and hydro-geology) (Joy, 2004).

But one commonality in most of the studies is the stress on public participation and involvement of community based organizations and NGOs. Shah (2006), who was the member of Parthasarathy Committee Report responsible for modifying the Hariyali guidelines of 2003, claims that one of the areas of concern in watershed development programmes is that these programmes are implemented by unmotivated, overworked, cynical, corrupt and fragmented government officials who fail to involve stakeholders. He also further mentions that the best work in watershed development has been done by the voluntary sector. This was reflected in the Parthasarathy Committee Report which focused on shifting the power from PRI institutions to voluntary sector.

But Deshpande, R.S. (2008) points out that creating a hype about the success of NGOs in watershed programmes and only highlighting their successes while putting their failures (which are far more in number) under carpet is a sort of fundamentalism which can prove detrimental to effectiveness of watershed programmes. It is sometimes evident that though the success stories due to NGO intervention are outnumbered by large number of failed projects, the impact of these success stories has been very large on policy and discourse of watershed development. Whether the involvement of NGOs has been really successful in bringing positive changes in watershed programmes probably requires a greater amount of study.

Regarding participatory approach, there have been studies done by Kumar S. (2007) about the sustainability of participatory approach by taking examples of watershed projects in Tamil Nadu. He pointed that there are various factors on which success of community participation depends, like homogeneous and small communities, dependence on large number of wells for irrigation, less rich-poor differences etc. And these factors are not common, and it results in many failed projects with participatory approach.

The studies on Hivare Bazaar and Ralegan Siddhi have pointed out that strong leadership is the key to successful community participation. Kerr (2000) points that NGO – government collaboration works better. Though everybody recognizes and appreciates the importance of participatory approach in watershed programmes, no concrete understanding about its implementation on ground has evolved. The understanding still rests on individual success stories.

In summary, there have been numerous studies and reports and analyses done to assess impact of watershed programmes, resulting in repeated institutional and philosophical changes in the watershed approach. But these studies and reports fail to give a complete picture of outcomes in wider context of sustainable development goals.

Rather than looking at the picture painted by individual successes or failures, it will be interesting to see the impact of watershed programmes at national level since 1995-96 based on indicators like land use pattern, irrigated area, drought prone affected area, contribution of agriculture to GDP etc.

2.4 A glance at national level indicators

2.4.1 Agriculture sector

The agriculture sector has not done well in last 20 years. The share of agriculture sector in GDP has consistently gone down since 1995. During the same period, the yield of principal food crops like rice and wheat has gone down (Reddy, 2010).

The number of cultivators has gone down whereas number of agricultural labourers has gone up. At the same time, the average size of land holding has also decreased since 1995 (Reddy, 2010).

Per capita agricultural income, which was half of the per capita national income during 1980s has become 1/3rd of the national income in 2010 (Reddy, 2010).

As an impact, large numbers of people are forced to leave agriculture in last 20 years due to different reasons. (Reddy, 2010)

Thus, agriculture sector as a whole has drastically gone down in performance in last 20 years. Although, there are numerous reasons for this, one cannot paint a glorious picture of watershed development programmes on this background.

2.4.2 Land use pattern

Land use pattern is one of the prime indicators for the success of watershed programmes. It's important to look at few national level land use indicators in order to see the impact of watershed programmes in past 15 years.

Net Sown Area

The net sown area (represents the total geographical area sown with crops and orchards, and is counted only once irrespective of number of sowings) has remained constant at 141 Mha from 1995 to 2009 (MoA, Agriculture staisticts at glance 2011).

If state-wise data is seen, most of the states have seen decrease in net area sown. Only Rajasthan and Gujarat have experienced a rise in net sown area. In Rajasthan, the rise is mainly due to tube wells and canal irrigation, while in Gujarat it is due to open and other wells and canal irrigation (CWC, 2010).

Gross Cropped Area

In the same period, gross cropped area (represents the total cropped area sown once and/or more than once per year and is counted as many times as there are sowings per year) has increased from 187.47 Mha to 195.1 Mha due to increase in net and gross irrigated area (MoA, 2011).

Net Irrigated Area

The net irrigated area (represents part of net area sown which is irrigated through any source and is counted only once per year irrespective of number of sowings) has shown increase from 53.4 Mha to 63.2 Mha. Also, the cropping intensity (ratio of net area sown to gross cropped area which shows the percent of geographical area sown which is cropped more than once per year) has increased from 131.8 to 138 (MoA, 2011).

The increase in irrigated area and cropping intensity may indicate positive impact of programmes at first glance, but if seen carefully, the irrigated area has increased mainly due to tube wells. 1990 onwards, tube wells have replaced canals as the principal source of irrigation. The irrigated area under tube wells was around 30 Mha in 1990, which has rose to around 42 Mha in 2008-09. Meanwhile, area irrigated by open wells has only increased from 10 Mha to 11.6 Mha in 20 years (CWC, 2010).

Digging of tube wells at greater and greater depths for irrigation has always been a worry from ecological and groundwater management point of view. So, the preponderance of tube wells actually reflects over-exploitation of groundwater and not success of watershed projects. The area irrigated by open and other wells which can be one indicator for success of watershed programmes, has marginally decreased from 2004 to 2009, which is a worrying fact while evaluating watershed programmes (CWC, 2010).

Other land use types

The area under miscellaneous tree crops (area which represents vegetative cover, but not included in net area sown) has not shown any increase (3.48 Mha in 1995-96 to 3.4 Mha in 2008-09) (MoA, 2011).

Area under culturable wasteland (which represents area available for cultivation, whether taken up or not taken up for cultivation once, but not cultivated during last five years or more in succession including current year. This land is fallow, covered with shrubs or jungles and can be put to agricultural use.) has decreased from around 15 Mha in 1995-96 to about 12.7 Mha in 2008-09. But this area is not put to any agricultural use as the net area sown in this period has not increased (MoA, 2011).

The total land available for cultivation but not cultivated (culturable wastelands + land under miscellaneous tree crops and vegetation but not included in area sown + fallow lands which are temporarily not cultivated for a period of less than 5 years) has not increased in last 20 years (from 41.42 Mha in 1995-96 to 41.021 Mha in 2008-09) (MoA, 2011).

The drought prone area in 2001 covered an area of 51.1 Mha which has expanded to 74.5 Mha in 2008-09. [Central Water Commission adopts two criteria for identification of block which is affected by drought –

- if annual rainfall is less than 75% of the normal in 20% of the years examined
- if the irrigated area goes down below 30% of the cultivated area

Thus, if any block is well irrigated, it won't be identified as a drought prone block even if it receives 75% less rainfall than normal.]

The Wastelands atlas prepared by National Remote Sensing Centre shows significant decrease in wastelands of the country, from 63.85 Mha in 2000 to 47.23 Mha in 2010. But this data does not match with the data provided by Ministry of Agriculture, which does actual accounting of land every year. The data acquired by NRSC is Resourcesat-1 LISS III data of resolution 1:50000. The classification system used by NRSC includes built up area, industrial area and permanent pastures as non-wastelands. Thus, the movement of land from wastelands to non-wastelands according to NRSC cannot be interpreted as increase in vegetative cover or movement of wasteland to cultivable area, and thus cannot be used directly as an indicator for success of watershed programmes, especially IWDP. (NRSC, Wastelands Atlas, 2011)

Regarding land degradation, which includes soil erosion by water and wind and other types of degradation like saline soils, alkali soils, acidic soils etc, there have been many studies at different points of time by different agencies like National Bureau of Soil Survey and Land Use Planning, ICAR (NBSSLUP), Ministry of Agriculture etc. According to study of NBSSLUP in 2004, the total degraded land in India was around 147 Mha, with area under soil erosion by water being 94 Mha. (ICAR, 2007)

The above facts also fail to show the satisfactory performance of watershed programmes in last 15 years.

Interesting fact is, there are no indicators which can tell about the contribution of watershed programmes in increasing net area sown, net irrigated area etc. The annual report of Integrated Watershed Management Programme just tells how much area was treated in that particular year along with budget outlays and expenditures. No accounting of benefits against costs is kept for the programme by MoRD. This gives rise to numerous impact assessment studies at individual or group of watershed programmes which have no official data and indicators to use.

2.5 A quick look at MGNREGS

2.5.1 Overview

Mahatma Gandhi National Rural Employment Guarantee Scheme, which was kicked off in February 2006, is one of the biggest national flagship programmes in India. The objective of the programme is to provide 100 days of wage employment on demand, to every rural household through public works which will create durable assets, improve water security, increase soil conservation and increase land productivity. Thus, the effect will be twofold; job through unskilled work for the short term and benefits through assets created for the long term. Thus, MGNREGA is said to have an integrated natural resource management and livelihoods generation perspective unlike earlier wage employment programmes. (MoRD, 2005 MGNREGA Act)

Total expenditure on MGNREGA since its inception up to 2011-12 is around Rs. 1,66,516 crores out of which around 66% has gone to rural poor as wages. Regarding asset creation, around 14.6 million works have been undertaken till now. The works fall under different categories like water conservation, water harvesting, drought proofing, land development, rural connectivity etc. Though MGNREGA is not a watershed programme, more than 50% of the public works done through the programme are related to soil and water conservation. Also, Twelfth Plan proposes to transform MGNREGA into the largest watershed programme, thus giving renewed energy to IWMP. Thus, a quick review on the impacts of MGNREGA on soil and water conservation needs to be taken. (Sameeksha – Anthology of research studies on MGNREGA, MoRD, 2011)

2.5.2 Impacts

Although, as per MoRD, per household wage earning has doubled between 2006-07 and 2010-11, the performance of assets created has been debated quite a lot. It has been reported that around 3.4 million water conservation structures built all over the country have added about 3.07 billion cubic meters of storage capacity during these 5 years. Irrigation facilities provided through MGNREGA works during the same time has added 6 million ha to irrigation potential (Sameeksha, MoRD). If these figures are considered true, the whole picture of rural India would have drastically changed.

But on ground, apart from the few sporadic success stories, the picture is completely contrary to above figures. There are huge administrative issues like delays in completion of works, wages paid against no work, works shown only on papers etc. but apart from these, the cases where the works are done successfully also don't seem to be fully functional due to improper technical design, wrong location of the structure and poor quality. (Down To Earth)

A study done (as a part of Social Audit of MGNREGA in 2012) in Mokhada block of Thane district in Maharashtra shows lack of proper engineering survey and design in NREGA works like mazgi (land development, terracing) and vanrai bandhara (temporary bund made of gunny bags filled with sand).

The vanrai bandharas / dagdi nala bunds constructed through MGNREGS were not planned scientifically. The decision regarding location of bunds was left to local people who think of the bunds only as an opportunity for employment. Thus most of the structures had no utility as assets or conservation structures. There was no study regarding the structure's impact on groundwater recharge, water table, soil runoff, increase in storage etc. before building the structure (Lokhande, N, 2012), (Mishra V and Belsare H 2012).

If MGNREGA is to be thought of as a major watershed programme, there has to be a standard framework for planning and design of such watershed structures, without which the huge efforts put in, in terms of money and labour, would remain only on the paper.

2.6 Broader agenda

In summary, it seems that too much shift away from the pure engineering and technical approach has led to a severe neglect towards credibility and durability of primary soil and water conservation activities. This has resulted in lack of on-field trained professionals / engineers who possess required scientific knowledge and important skills like map-reading, surveying, analyzing, planning etc. (Sohoni). At the same time, more stress on public participation has created a huge space for non-professional, good intentioned voluntary organizations in planning of watershed activities which has pushed the focus from core engineering activities even further.

But the technical side of the watershed programme should not be separated from the socio-economic side this way. Collaboration with local people and their participation is an inherent and absolutely necessary step in proper scientific planning. But the whole process of planning does not stop here. It requires transforming the socio-economic needs of the people into technically correct plans in order to deliver success. This includes essential technical knowledge and skills like the ones mentioned above.

Currently there is an urgent need of such trained manpower in watershed planning. This trained workforce should come from local colleges and schools and should transform the barefoot professionals working for voluntary organizations into trained watershed planners who would possess analytical skills to ask right questions, do right measurements and surveys, use scientific knowledge and technology to decide locations of structures and predict outcomes etc.

Such training would require a broader knowledge and practice framework based on set of good practices in planning of watershed interventions. The present study is motivated by the need of such knowledge and practice framework by focusing on solving a drinking water problem in Mograj by planning for appropriate watershed intervention.

Chapter 3 - Need for more rationality in planning – Context for the present study

3.1 Watershed as a physical system

History of watershed programmes in India shows how it has evolved from purely technical and engineering interventions to a programme aiming at holistic development of rural economy. Though the importance of sound technical planning in watershed development is appreciated by many (Kerr, Joy, Parthasarathy etc.), it seems that the evolution of participatory approach has sidelined the evolution of technical discourse in watershed planning.

Though watershed development is now considered as a social organization problem, fundamentally it is defined as a geo-hydrological unit; A unit from which the rainwater drains through a single outlet. Thus, it is a physical system with clear boundaries and some definite parameters like –

- Quantum of rainfall
- Terrain i.e. slopes, contours etc.
- Soil type and depth
- Aquifer characteristics
- Water balance
- Groundwater and surface water regimes

Thus, planning for any physical watershed intervention, may it be for soil / water conservation or land development or forest conservation would require understanding of the above attributes in order to have a positive impact. The problem of social organization and of sharing benefits only comes once the watershed plan is done correctly and is able to bring benefits in the first place.

Without proper planning and understanding of the watershed attributes, the efforts put in mobilizing, participation and creating auxiliary livelihood opportunities would go waste. Simply put, a withdrawal strategy of investing in cross-breed cows for improved livelihoods in a region where there is drinking water shortage would go terribly wrong if water availability in the region does not increase drastically. Similarly, efforts to bring in community participation or increase gender equity like building self-help groups or *bhajni* *mandals* or desilting a water body may only give short-term benefits if watershed activities fail due to improper planning.

3.2 Aquifer mapping

12th plan talks about groundwater recharge and watershed restoration as primary requirement for major breakthrough in rain-fed areas. At the same time, more stress is being given on aquifer management and aquifer mapping. It is understood that management of common property resource like groundwater requires clear delineation of boundaries. Dr. Himanshu Kulkarni, member of Planning Commission on groundwater management argues that watershed boundaries don't always match aquifer boundaries, which may create conflicts in management of groundwater resource (Working group, sustainable gw mgmt). Thus, a shift from watershed or revenue boundaries to aquifer boundaries is necessary. Accordingly, more stress is being given in 12th plan on aquifer mapping and aquifer management (12th plan).

This shift will not be trivial, because then, the aquifer characteristics (like transmissivity, specific yield, confined / unconfined etc.) will become important in planning for structures. This requires evolution of practices for detailed scientific understanding of hydrogeology, groundwater flow regimes etc. for catering to the needs of aquifer management and planning.

3.3 Scientific planning in IWMP

IWMP guidelines show serious concern about scientific planning in watershed programmes –

"*…programmes suffer from the serious lacuna of the absence of detailed scientific planning, at present. There has hardly been any attempt to harness available technologies or to coordinate with organizations such as National Remote Sensing Agency (NRSA). The IWMP will look at the incorporation of scientific planning methodologies."*(DoLR, 2008)

Guidelines also talk about incorporating GIS (Geographical Information System) and GPS (Global Positioning System) to aid planning. Such steps should be welcomed as these technological interventions will surely increase verifiability in planning.

But at the same time, detailed scientific planning involves much more than use of high-tech equipments / data. Scientific planning in case of watershed programmes should involve standard practices like (i) acquiring right (primary as well as secondary) data by asking right questions and doing right surveys, (ii) representing / modelling the watershed based on the data correctly, (iii) analysing the data and making plans based on the analysis.

These set of practices further involve meetings and discussions with people for collecting primary local data like location of water sources, streams etc., collecting required secondary data like rainfall etc., careful observations on the field like water levels in the wells, land ownership etc., detailed ground surveys like trial pits, bore holes, dumpy surveys etc., use of appropriate modelling techniques like hydrological modelling, GIS etc. for representation, rigorous analysis and predictions and then planning accordingly.

There is a serious lack of such practices in watershed planning presently. Only 1% of the total project funds are allocated for planning. The outcome of this planning is a DPR (Detailed Project Report) which is to be prepared by PIA with the help of WDT (Watershed Development Team). WDT is a part of PIA having planning expertise. PIA can be an NGO or government department like TAO (Taluka Agriculture Office). PIA with the help of WDT is supposed to do all the required field investigations, surveys, data analysis and planning in the project. Surprisingly, there is no requirement as per guidelines for a PIA or WDT to have a trained engineer as a part of it. (DoLR, 2008)

3.4 What goes into IWMP DPR?

A careful study of one such IWMP DPR, prepared by TAO, Karjat reveals interesting facts. The region is tribal and economically backward. Temporary or even permanent migration for search of labour is high. More than 90% farming is rain-fed. In spite of heavy rainfall, there is drinking water shortage during dry months. Out of around 2000 ha land to be treated, half of it is presently uncultivated, around one-third temporarily fallow or pasture and the remaining is cultivated. (TAO, Karjat, IWMP, DPR)

The project aims for the following –

- Reduction in migration from 2182 persons to 1091 persons in rabbi season due to increase in water availability during rabbi season
- Rise in water table below ground level from 5.5 m to 2.1 m
- End to drinking water scarcity
- Increase in irrigation potential to 66% (currently almost nil)
- Increase in rain-fed area by 520 ha, forest area by 110 ha, area under fodder and fuel-wood by 35 ha
- Increase in productivity from 743 quintals to 1553 quintals
- Reduction in rainwater runoff by 2394 TCM (thousand cubic meters)

The report attaches remote sensing data maps (provided by MRSAC – Maharashtra Remote Sensing Application Centre, which has signed MoU (Memorandum of Understanding) with

Agriculure Department of Maharashtra). These maps provide information like soil texture, soil depth, slope, drainage, village-wise land holding data etc. at 1:40000 or 1:65000 resolution. But report does not tell anything about how this data was used in planning and presents absolutely no reasoning or logic for the expected outcomes nor any scientific basis for planning.

Similar DPR prepared for a micro watershed in Mokhada block by TAO, Mokhada also boasts of such expected outcomes without providing any reasoning.

The problem with such DPRs does not seem to be of integrity or capacity of the PIA team. The DPRs reflect the neglect towards scientific and outcome-oriented planning which comes from a broader philosophy.

3.5 Context for the present study

Whether it is IWMP or MGNREGS or even the sustainability component of NRDWP, the smallest unit of watershed intervention is always a soil or water conservation work like contour trenching, *mazgi*, check dam etc. The success of these works depends on proper scientific understanding and planning which requires a standard framework of practices. Following is the framework which will be used in the present study to solve drinking water problem in Mograj through appropriate watershed interventions.

Table 2 - Knowledge and practice framework for watershed planning

Step	Data to be collected	Tools used
Understanding the needs (socio-economic understanding)	Informal meetings with people	PRA (Participatory Rural Appraisal), household interviews, informal discussions etc.
	Having rough idea about the geography and social dynamics of the region through resource maps, social maps, transect walk etc.	
	Understanding of the problems through focused discussions	
	Secondary data collection like demographics, other ongoing schemes, past schemes (successful and failed), current status of the village (tanker-fed or not etc.)	
	Prioritising the needs (e.g. drinking water, livelihood water, drinking water quality etc.)	
Understanding the watershed – terrain	Locating all the sources of water during transect walk along with marking in Google	GPS (Global Positioning System), GIS (Geographical

data	Maps / Earth through GPS	Information System), Google Maps, toposheets
	Identifying site for the intervention and proposing possible interventions based on intuition	
	Acquiring toposheets, contour maps etc. from concerned government departments (agriculture office, forest office etc)	
	Generating terrain data through DEM (Digital Elevation Model) from Bhuvan ISRO, or through Google Elevation data using GIS	
	Ground truthing of generated data by actual surveying using Dumpy or TotalStation	Dumpy, TotalStation
	Delineating watershed boundary by using generated terrain maps, marking streams, drainage lines, ridge area, water bodies, wells etc on the maps through on-field investigations and survey	GIS
Understanding the watershed – Rainfall data	Collecting rainfall data for last five years	Through nearby rain gauge
Understanding the watershed – Soil data	Collecting soil maps from soil survey laboratories / agriculture office	Soil maps, soil sampling, permeability tests, infiltrometer tests
	Collecting soil data from field by trial pits and collecting samples	
	Doing soil testing for finding out texture, conductivity etc.	
Understanding the watershed – Rock data	Doing rapid geological survey for knowing the geology of the area like types of rocks, rough depths of layers of different rocks etc.	
	Doing resistivity surveys for investigating exact geological picture under the surface	MERI (Multi-Electrde Resistivity Imaging) survey
Understanding the watershed – Well data	Collecting water level data in wells through constant monitoring	Well monitoring and inventory
	Collecting secondary data like observation well data (if nearby), groundwater potential data if available, rock characteristic data (e.g. specific yield, storage etc.), soil data	

	(conductivity, texture etc)	
Representing the watershed	Incorporating all the collected data in a model (groundwater model in this case), running steady-state and transient models to caliberate and validate the model in order to match on-field conditions,	MODFLOW, GMS (Groundwater Modelling Software),
Analysing the impacts / outcomes of proposed interventions	Modelling of proposed interventions, studying impacts of the interventions on parameters like increase in levels of water in well, increase in overall storage of water, reduction in water runoff etc.	GMS
Planning and implementing	Coordinating with people and government officials for proper implementation of the intervention through MGNREGA	Meetings with people, officials

Mograj

The water security problem in a small tribal hamlet of Mograj in Karjat block of Raigad district will be solved using above framework / methodology. The main steps involved in solving the problem will be as follows:

- Understanding the needs (interaction with people)
- Understanding the terrain (gathering primary as well as secondary data from various sources)
- Modelling the watershed
- Proposing intervention based on the analysis and simulations

Chapter 4 - Mograj case study

4.1 About Mograj

4.1.1 Geography:

Mograj is a small tribal habitation in Mograj gram panchayat of Karjat block in Raigad district of Maharashtra. It is located in the northern part of Karjat block, in the foothills of Western Ghats. Mograj is a typical habitation in Western Ghats region with similar geography, geo-hydrology and climate. Hence, it will be useful to know a little bit about Western Ghats region.

Western Ghats, also known as Sahyadri mountain range stretches from the border of Gujarat and Maharashtra states and runs southwards parallel to the western coast through states of Maharashtra, Goa, Karnataka and Tamil Nadu, ending in southernmost tip of Kerala. These mountains separate Deccan Plateau from a narrow coastal plain on the western part. These mountains were formed around 60-68 million years ago due to series of huge volcanic eruptions. These are igneous rock mountains, made of several layers of basalt (Wikipedia)

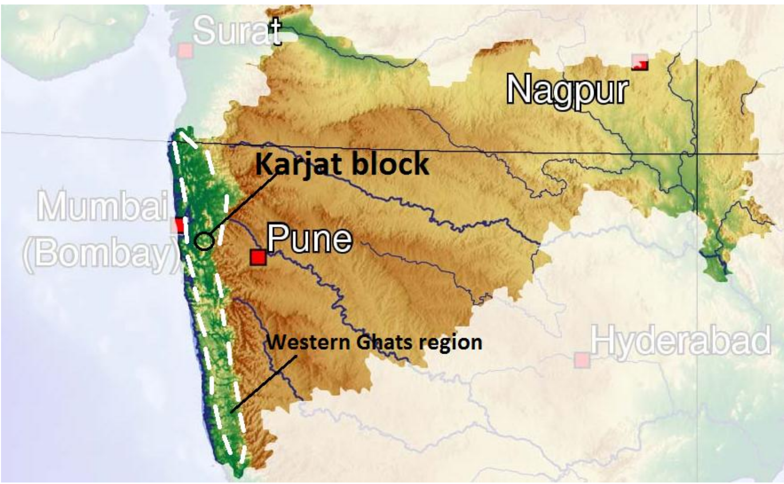


Figure 4-1 – Karjat block, Maharashtra

Western Ghats in Maharashtra receive very heavy rainfall (3000 – 6000 mm per year) from south-west monsoons i.e. June to September. But due to undulating hilly terrain and low storage capacity of basalt aquifers, most of the rainwater runs off quickly. Groundwater occurs in weathered parts, fractures and joints in basalt. Depth of the wells in the region ranges from 3.5 m to 8.5 m below ground level. The yield of the wells in the region is poor to moderate and majority of the wells go dry in summer season due to poorly productive aquifer (GSDA).

4.1.2 Locating Mograj

Table 3 - Latitude - Longitude of Mograj

Village	Latitude	Longitude	Elevation above mean sea level (m)
Mograj	18.9961711	73.4748673	145

Karjat is the north-east corner block Raigad district. Karjat block is surrounded by Thane district in the north, Pune district in the east and Khalapur and Panvel blocks of Raigad district in the south and west respectively. The eastern boundary of Karjat i.e. the boundary separating Raigad and Pune district is lined by Sahyadri mountain range. Mograj is situated very close to the eastern boundary in the northern part of the block. Mograj is situated around 30 km by road from Karjat town, the headquarters of Karjat block.

The nearest railway station is Neral which is also around 30 km from Mograj. The nearest market place is in a small town, Kashele, located on Karjat-Murbad highway around 6-8 km from Mograj (Murbad is a block in Thane district).

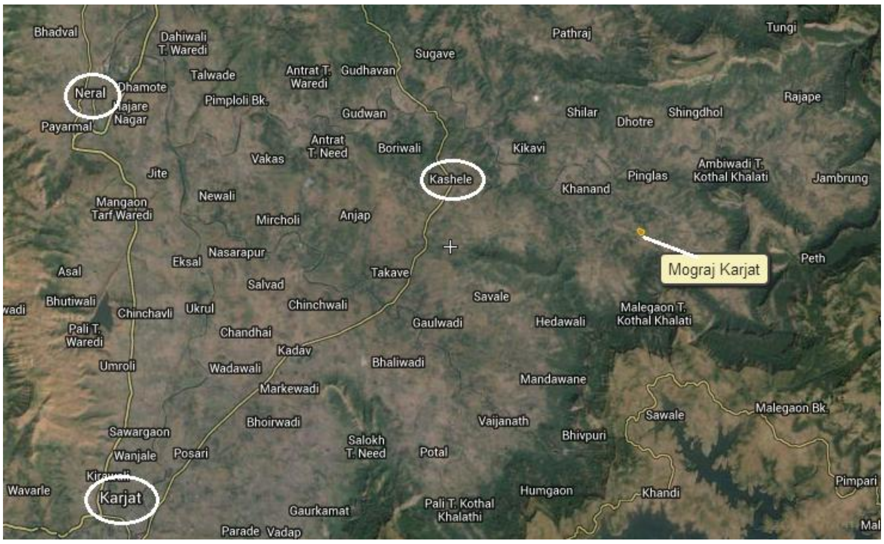


Figure 4-2 – Mograj map

4.1.3 Demographics

Habitation Profile

** Data shown here may change as state are doing yearly data updates till June 2013 end

State: MAHARASHTRA	District: RAIGAD	Block: KARJAT
Panchayat: MOGRAJ	Village: MOGRAJ	Habitation: MOGRAJ

Abstract Data

No. Of Households (As On 01/04/2003)	63		
No. Of Cattles (As On 01/04/2003)	200		
Total Population (As On 01/04/2009)	GEN - 15	SC - 0	ST - 411
Population Covered As On 01/04/2013	GEN - 15	SC - 0	ST - 411
Water Quality Contamination	None		
Targeted In 2013-2014	No		
Water Supply Coverage Status As On 01/04/2013	Covered		
Water Supply Coverage Status As On Date	Covered		

Figure 4-3 – Mograj habitation profile (NRDWP website)

As per census data 2001, there are 63 households in Mograj. According to the household survey carried out during in 2013, there are 75 households in Mograj. The total population of Mograj is around 430 souls out of which around 98% are tribal (around 70% *thakars* and 30% *katkaris*).

4.1.4 Agriculture and Economy

The whole Western Ghats region in Maharashtra is characterized by rainfed agriculture. The prime crop is paddy which is grown on terraced lands in the hills. Other crops like *varai*, *nachni* are grown on hill slopes.

The incomes of the people are meagre and public services (sadak, bijli and paani) are in poor condition. Apart from activities during rain-fed agriculture, people have no activities for rabbi season. They migrate to nearby towns like Karjat, Kashele, Neral etc. as well as big cities like Badlapur and Kalyan for labour work. MGNREGA works are not popular in the region because the MGNREGA wages are too less than the market rate for labour in the region and also because there are huge delays in getting wages through MGNREGA.

4.1.5 Drinking water problem

Like many villages in the Western Ghats region, Mograj also faces drinking water scarcity during dry months (March to June). The problem in Mograj has persisted for last many years. Water Group, CTARA, has done few studies in Mograj to understand the drinking water scenario (Shyamal, S, Vishwanathe, S, 2012), (Belsare, H et. al. 2012). On this backdrop, it was decided to study and understand the watershed of the region in order to improve the drinking water condition of the village.

4.2 Understanding the needs

4.2.1 Participatory Rural Appraisal for understanding drinking water scenario

During previous study done by Water Group, CTARA in May 2012 (Belsare, H et. al, 2012), a PRA exercise was carried out in Mograj in order to understand the existing water scenario and for identifying needs of the villagers. The resource map drawn by the villagers during the exercise was used to have a rough estimate about the overall topography of the region and various water sources used by the people.

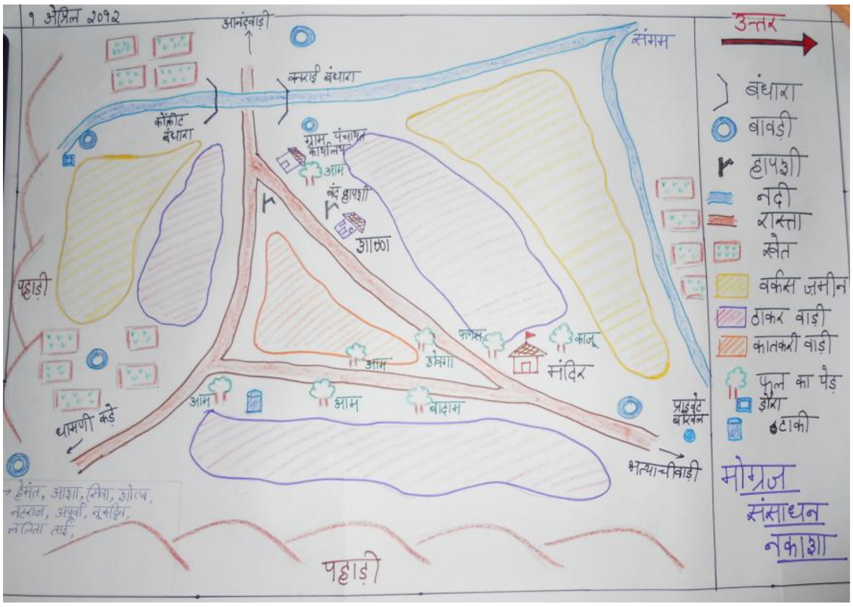


Figure 4-4 – Mograj – PRA (2012)

4.2.2 Drinking water scenario through meetings with people

Along with the information acquired through previously done PRA exercise, fresh meetings and interviews with people were held in order to have a detailed understanding of the drinking water scenario.

Currently, people fetch water from four main sources in and around Mograj. Out of these three sources, three are open dug wells (public well 1, public well 2 or *varchi well* and *chinch-nalichi well*), one is hand pump. Primarily people depend on the hand pump and public well 1 (closest to the village) for domestic water needs.

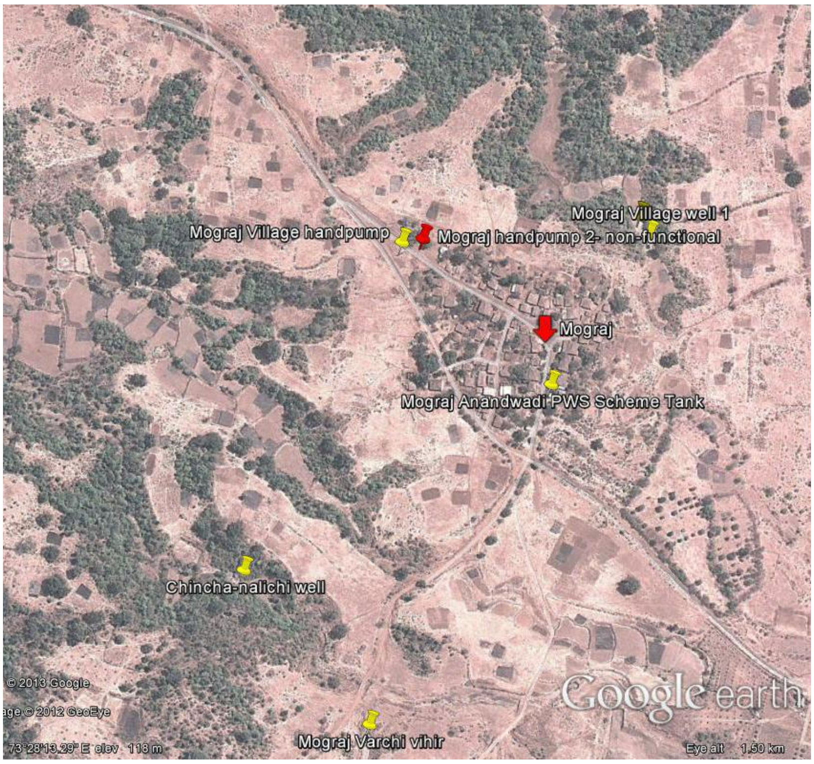


Figure 4-5 – Mograj drinking water sources

Public well 1 dries in January itself, after which almost all people depend on the hand-pump. Due to burden on hand-pump bore, it starts drying up around mid February after which part of the village start fetching water from public well 2 which is around 500 m south of the village. Gradually the hand pump becomes very difficult to operate and most people start depending on the public well 2, which eventually dries up around 1st week of April.

Chinch-nalichi well which lies to the south of the village is used only as a last resort by the people as it is very difficult to access. Only some villagers fetch water from this well also but eventually it also dries around April end.

In May, public well 2 / *varchi* well and the hand pump are the only two sources left. At the hand pump, people have to wait for 1 or 2 hours to fill one *kalsi* (pot for fetching drinking water which women carry on their head). Similar is the situation at *varchi* well. This well has a spring which never dries up. But the water just trickles very slowly from the spring. So people queue up for water at both the sources. The other option is to travel long distances to wells in other habitations or to private wells which are 1-2 kms away from the village. Following are the details of all the water sources for Mograj habitation. The sources highlighted in blue colour are those which are most commonly used by the villagers.

Table 4 - Mograj: Drinking water sources

Water source	Type	Ownership	Distance	Depth	Water availability
Public Well 1	Open Dug well	Public	100 m	10 ft	Till January
Public Well 2	Open Dug well	Public	500 m	25 ft	Till 1st week April
Hand pump 1	Bore	Public	Non functioning	-	-
Hand pump 2	Bore	Public	50 m	100 ft	Till April
Chinch-nalichi well	Open Dug Well	Public	750 m	20 ft	Till April
Farm house well	Open Dug Well	Private	1 km	20 ft	12 months
Purshottam Patil's Well	Open Dug Well	Private	1.6 km	25 ft	12 months
Anandwadi well	Open Dug well	Public	2 km	25 ft	12 months
Chaudharwadi well	Open Dug well	Public	2.5 km	-	12 months
Private bore well	Bore	Private	Not in use presently	100 ft	-

4.2.3 Non-functional piped water supply scheme

In spite of this scenario there is no tanker-supply to the village because the village is officially having a functional piped water supply scheme (according to NRDWP database)

Table 5 - Mograj Piped Water Supply Scheme

Water Sources Reported												
S. No.	Source Type	Source Type Category	Location	Status	Scheme Details							Functional
					Scheme Name - SchemeId	Sanction Year	Est. Cost (Rs. In Lakh)	Rep. Exp (Rs. In Lakh)	Commen. Date	Est. Completion Date		
1	Openwell	Ground Water	NEAR FIELD	Safe	MOGRAJ ANANDWADI PWSS-(0004446565)	2003-2004	8.27000	8.00000	25/05/2003	19/10/2004		Yes

source – nrdwp website

The source for the scheme is *Anandwadi* well which is around 2 km from the village. The scheme is/was designed to pump water from *Anandwadi* well and store it in a GSR (Ground Storage Reservoir) built in the village. The GSR can be seen in the village, but is not in use for last many years. The scheme which was completed in 2004 was functional only for few days according to the villagers. Since then the scheme has never worked. But in NRDWP database the scheme is reported to be functional, and hence Mograj is not listed in water-scarce villages.

4.2.4 Water consumption data - acquired through interviews

Average water consumption per household of 4 people in Mograj village is about 100 – 200 litres per day depending on the water availability. This water is used for drinking, cooking, washing utensils and bathing. During and just after rainy season, when water availability is good, per capita per day consumption of water is about 50 litres, which drops down to 25 litres or even less during scarcity period (i.e. post March).

Three distinct patterns of water consumption according to water availability can be marked very clearly –

Table 6 - Mograj water consumption data

Phase	Water consumption per household (litres per day)
June to October	200 or more
October to March	100 – 150
March to June	100 or less

4.2.5 Site identification for watershed intervention

After studying the resource map as well as Google map of the region, it was decided to have a detailed survey of all the drinking water sources along with the surrounding topography, vegetation and land ownership. A transect walk with a fairly aged villager *Bhau Agivale* was carried out. Each and every water source within the boundary of the habitation was investigated along with their locations on GPS (Global Positioning System), the duration for which the source is active, it’s distance from village, dependence of villagers on the source, it’s type (private / public, open well / bore well) etc. was noted.

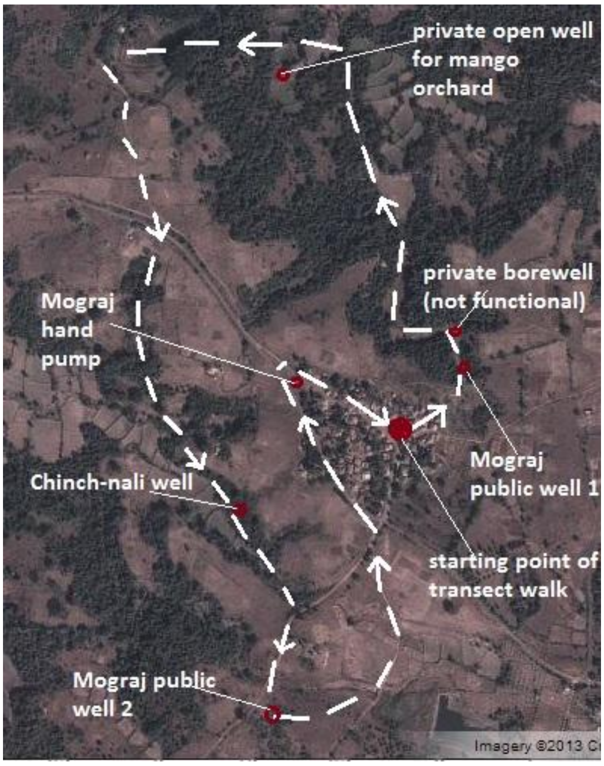


Figure 4-6 – Mograj: Transect walk

It was found out that the wells Public well 2 / *varchi well*, Public well 1 and *chinch-nalichi well* need source strengthening and should be considered for some watershed treatment.

About Mograj Public Well 2 / varchi well

Public well 2 / *varchi well*, which is around 500 m south of Mograj habitation was chosen for current study. The reasons behind choosing *varchi well* are –

- Most of the land upstream of the well is fallow and conflicts of land ownership would be less if watershed intervention like contour trenches or plantation is planned
- Slope of the land above the well is suitable for watershed treatment
- Almost whole village depends on the well during months of February to April (i.e. till there is water in the well)
- The village is not too far from the village and the access path to well is not difficult
- The well is in good condition and is recharged by a small spring till the end of dry season

The well is located in the stream (i.e. drainage line) whose watershed is approximately 5 hectares. A preliminary observation of the region above the well during transect walk suggested that the region was suitable for watershed interventions (a check dam in the stream or contour trenches in the ridge area etc)

Load on varchi well

Varchi well is used only by few people (whose houses are close to the well) during June to February. Only after other wells start drying, people from whole village start fetching water at varchi well. Thus, after February, the load on the well increases and keeps on increasing till it completely dries.

Table 7 - Mograj water consumption data - seasonwise

Phase	**No. of households depending on varchi well per day**	**Water consumption per household (litres per day)**	**Total withdrawal of water from varchi well per day (cum)**
June – February	~ 20	200	4
February - March	40	150	6
March – till the well dries	75	100	7.5

4.2.6 Outcome

From different exercises like PRA, interviews and meetings with people etc. it was confirmed that the immediate need of the village is solution to drinking water problem. During the process it was found that the *varchi* well is an ideal source to be strengthened. Hence the focus of the present study is to design a watershed intervention in order to increase water levels in *varchi* well in order to alleviate the drinking water problem of the habitation.

4.3 Understanding the watershed

4.3.1 Terrain data

Preliminary survey of watershed

The terrain in this region is undulating with large number of small hillocks creating many small streams during rainy season. The catchments of all these streams are small and are disconnected from each other. These form number of small watersheds. Also, it can be assumed that groundwater flows follow surface water flows thus matching aquifer boundaries with the watershed boundaries. This assumption was verified through detailed inspection of the ridge area of the watershed.

During site investigation, watershed boundary was traversed and marked by GPS by walking over the ridge. Thus, rough watershed boundary based on simple observation was identified on Google Map with the help of GPS data.

Figure 4-7 – Mograj watershed – Marked through GPS

Secondary data

For delineating the boundary, high resolution contour data of the region is required. For the watershed region under focus which is around 5 hectares, a contour map of at least 1:5000 or 1:8000 resolution is required. Such toposheets were not available in Karjat block agriculture office, neither at district agriculture office nor at the state agricultural office in Pune.

The maps used by agriculture office for IWMP are produced by MRSAC, Nagpur. They are of resolution 1:50000 or 1:65000 and are based on remotely sensed data. These maps cannot be shared by agriculture department with anyone because of MoU between Agriculture Department and MRSAC, Nagpur.

DEM - Bhuvan

Bhuvan web application developed by ISRO gives 1 arc-second resolution satellite maps in DEM (Digital Elevation Model) format. These are also low resolution maps which are useful for regions which are at least 5000 hectares large.

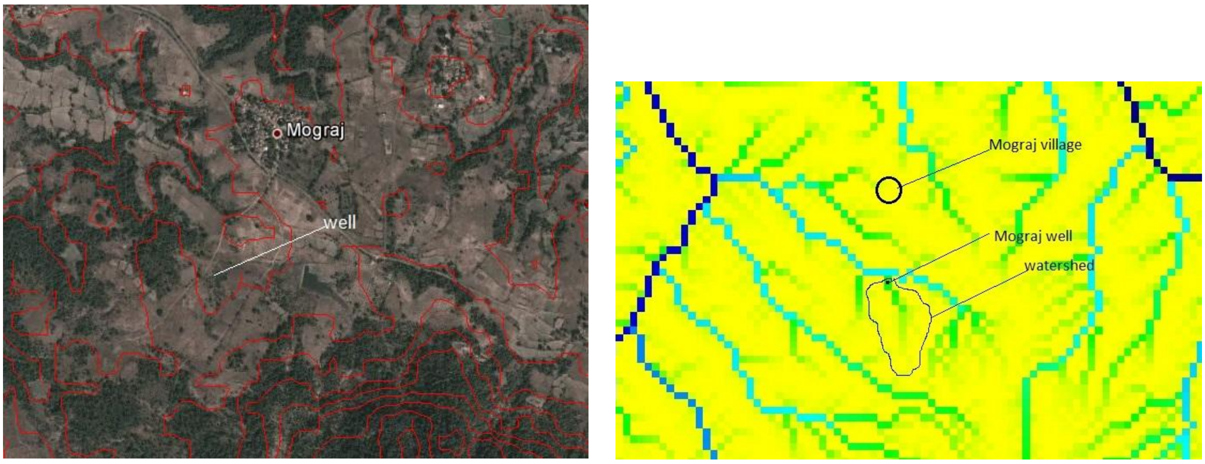


Figure 4-8 – Mograj contour map (left) and drainage map (right) in GIS (Bhuvan data)

Google APIs

The other option is to fetch elevation data through Google APIs (Application Program Interfaces), which allows interaction with various Google Services. One such API is Google Maps Elevation API which returns elevation data for any location on the earth.

Google doesn't have exact elevation for each point on the earth. In those cases where Google does not possess exact elevation measurements at the precise location of request, the service interpolates and returns an averaged value using the four nearest neighbouring locations.

Hence, the data returned by Google Elevation API is also not accurate. The satellite used by Google also gives data with 1 arc second resolution. But it was observed that the point data obtained from Google gave more accurate data than Bhuvan.

A simple JavaScript based web-application was written to acquire elevation data of points in the watershed. The application displays a Google map of the study region (latitude – longitude of some point in the study region needs to be entered). A grid which covers the whole watershed needs to be marked on the map. This can be done by giving north-east and south-west corners of the grid (by entering respective latitudes and longitudes). After marking the grid, the grid is divided into some fixed number of points in x and y axes say, 5 by 5 or 15 by 15. These points are then sent to Google API whose elevation is returned by the API and is output in the form of comma-separated sheet (CSV format).

Figure 4-9 – HTML Application for fetching Google API data

There is a restriction to number of points sent in one Elevation request to Google API. The total number of points in the request should be less than 400. The grid points, along with the elevation for each point, are used to construct the watershed terrain in GMS / GIS. The data returned by the application is in following format –

	A	B	C
1	Latitude	Longitude	Elevation
2	73.47249	18.98952	143.728134
3	73.47267	18.98952	144.514557
4	73.47285	18.98952	145.300995
5	73.47304	18.98952	146.131119
6	73.47322	18.98952	147.051544
7	73.4734	18.98952	148.103821
8	73.47358	18.98952	149.156082
9	73.47376	18.98952	150.208359
10	73.47395	18.98952	151.80864
11	73.47413	18.98952	153.518127

Figure 4-10 – Data returned by Google API

Ground truthing and error correction in Google Elevation data

The elevations returned from Google Elevation API are not accurate and are calculated from four nearest neighbours by interpolation. Thus, the surface created from these points may not show some features like small hillocks or streams as they are. Generally, Google API may go wrong at locations where there is a sudden rise or fall in elevation on real surface. Hence the data returned from Google API needs correction.

The error correction was done by measuring actual elevation of some points in the watershed. First, well as benchmark point was decided. The elevation of this point as returned by the Google API was assumed to be accurate and was treated as the benchmark. Then some 10-15 other points in the watershed were selected. The points were chosen so that they covered ridge area, drainage line as well as the region in between, but no standard procedure was applied. Their relative elevation from the benchmark was measured using Dumpy Level.

The relative elevations of the chosen points were compared with the elevations obtained from Google API. After comparison, the error in Google API elevations at different locations became clear. A pattern in the error values was seen according to the position of the point. The error values were higher in the drainage line and slowly decreased towards ridge area. Accordingly, the points were divided into three regions, drainage line, ridge area and points in between. Mean error was calculated separately for each region and was applied to all the points in that region.

In the following image, the points in yellow represent the points in drainage line i.e. stream, the red points are the points in the ridge area while the blue ones are the points in between.

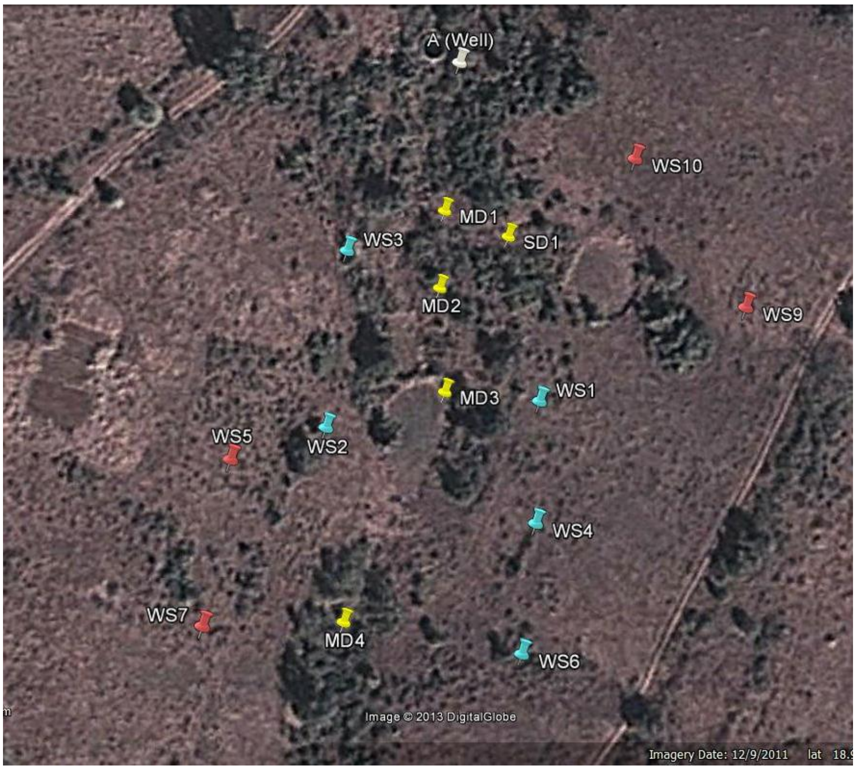


Figure 4-11 – Points chosen for dumpy survey

Lesson learnt

The number of points to be chosen for Dumpy Level survey and their locations were chosen mostly by intuition. A standard procedure can be developed for this by understanding how Google API works. This is relegated to future work.

Table 8 - Error correction of Google API data

Latitude	Longitude	Point Name	Dumpy Reading	Google API Reading	Absolute Error (Dumpy Reading - Google Reading)	Relative Error (Absolute Error/Dumpy Level Reading*10)	Mean Error For Each Subset of Absolute Error	Corrected Elevation (Google API Reading + Mean Error)	New Absolute Error (Dumpy Reading - Corrected Elevation)	New Relative Error
18.99221	73.4735	A	135.9786	135.9786	0	0	0	135.9786	0	
18.99187	73.4736	D1	137.7686	136.9974	0.7712	0.055977922	-0.0576	136.9398	0.8288	0.0601588
18.99192	73.47347	MD1	136.3686	136.5374	-0.1688	0.012378216	-0.0576	136.4798	-0.1112	-0.0081544
18.99177	73.47346	MD2	137.2386	137.2833	-0.0447	0.003257101	-0.0576	137.2257	0.0129	0.00094
18.99157	73.47347	MD3	137.9986	138.3195	-0.3209	0.023253859	-0.0576	138.2619	-0.2633	-0.0190799
18.99114	73.47327	MD4	139.3586	139.8834	-0.5248	0.037658243	-0.0576	139.8258	-0.4672	-0.033525
18.99155	73.47366	WS1	141.4086	138.8504	2.5582	0.180908375	2.409672	141.260072	0.148528	0.0105035
18.9915	73.47323	WS2	140.1586	138.1086	2.05005	0.146266444	2.409672	140.518222	-0.359622	-0.0256582
18.99184	73.47327	WS3	139.8586	136.6161	3.2425	0.231841303	2.409672	139.025772	0.832828	0.0595479
18.99132	73.47365	WS4	141.4586	140.0868	1.3718	0.096975369	2.409672	142.496472	-1.037872	-0.0733693
18.99108	73.47362	WS6	144.1286	141.3028	2.82581	0.196061712	2.409672	143.712462	0.416138	0.0288727
18.99144	73.47304	WS5	142.5286	138.3753	4.1533	0.291401164	4.62952	143.00482	-0.47622	-0.0334122
18.99113	73.47299	WS7	144.4186	139.591	4.8276	0.334278272	4.62952	144.22052	0.19808	0.0137157
18.99081	73.47316	WS8	144.8086	141.0026	3.806	0.262829694	4.62952	145.63212	-0.82352	-0.0568696
18.99173	73.47408	WS9	143.7386	138.5386	5.2	0.36176782	4.62952	143.16812	0.57048	0.0396887
18.99202	73.47386	WS10	141.9486	136.7879	5.1607	0.363561176	4.62952	141.41742	0.53118	0.0374206
		Average Errors			2.327197333	0.173227778			1.8948E-15	5.195E-05

Generating contours and delineating actual watershed boundary

The corrected elevation data was then used to generate the watershed terrain in GMS. This terrain was a close representative of the actual terrain and was able to show all the drainage lines and other features clearly.

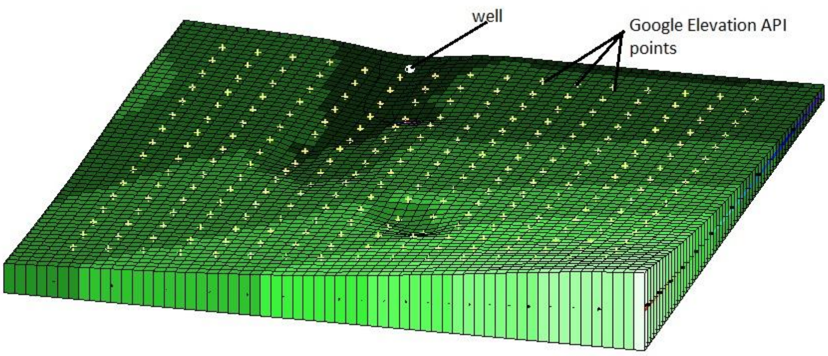


Figure 4-12 – Surface generated from corrected Google API data

Based on this terrain, contours were generated in GMS which were used to delineate the accurate watershed boundary.

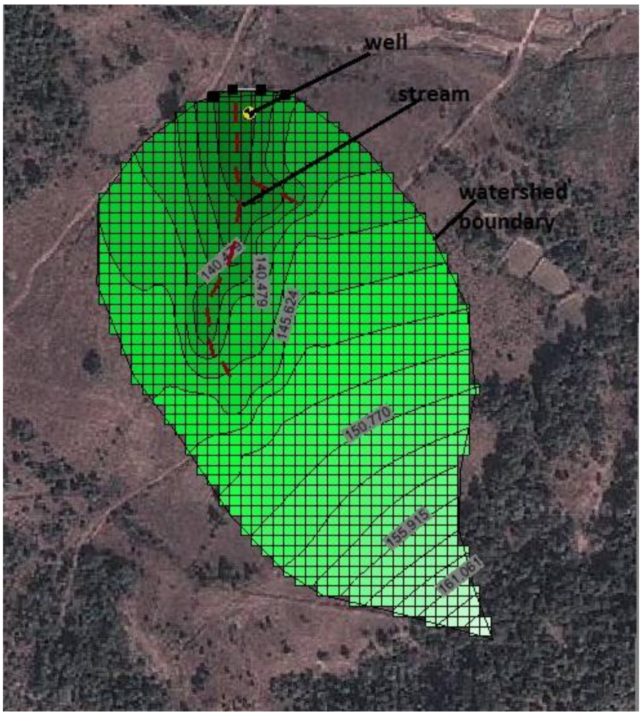


Figure 4-13 – Mograj watershed boundary marked with the help of contours

4.3.2 Soil data

In order to understand the groundwater as well as surface water flow in the watershed, proper understanding of the soil characteristics is required. Soil type, its permeability, depth of soil layer, its holding capacity etc. are important factors to be considered while deciding the type of structure to be built.

Soil maps

Soil characteristics like soil type and depth can be known from soil maps of the region. The Soil Survey sub-department of Agriculture department in Maharashtra has done gram panchayat-level soil surveys of whole Maharashtra during 1980s and 90s. For each gram panchayat, a Field Book is maintained. The Field Book has details about soil samples taken from all the land holdings (survey nos.) in gram panchayat. It contains details like depth of soil layer, clay-silt-sand content of soil, its water holding capacity, NPK proportion etc. and can be very useful for watershed planning. The Field Book is generally available at the Soil Survey Laboratory at respective district's headquarters. In case of Mograj the field book should be available at Alibaug Soil Survey Laboratory. Contact with the person in charge could not be made and hence the field book could not be obtained.

Primary data – Trial pits

The data in the field book was collected in 1980s and hence not reliable. Hence it was decided to collect primary soil data i.e. depth of soil layer and conductivity. For this, trial pits were dug at different locations in the watershed. The locations for the pits were decided as per following conditions – on both sides of stream, close to stream and in ridge area.

The pits were dug till the hard *murum* was not encountered. The pits were dug by local people and were paid according to the local market rates by the institute. Following were the locations of the pits.

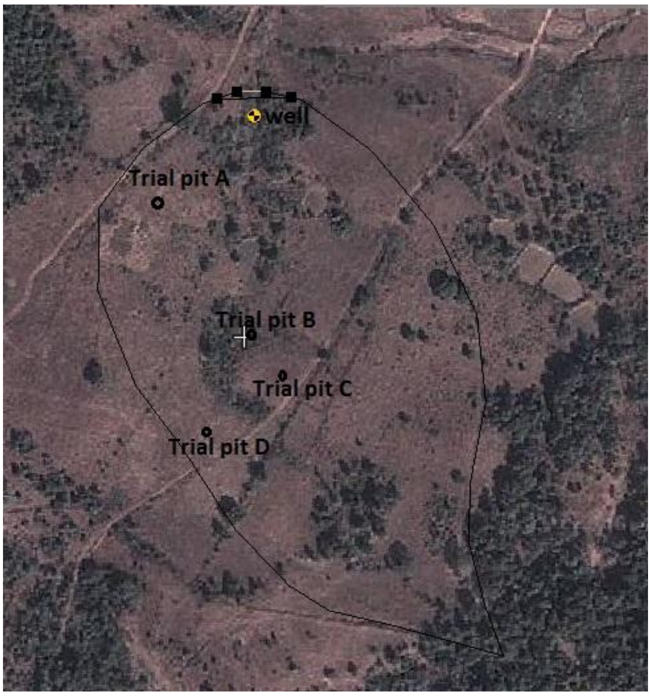


Figure 4-14 – Trial pit locations

Primary data collected from the trial pits is as follows –

Depth of soil layers

The depths at which hard *murum* was encountered were noted. It was noted that the depth of soil layer is minimum near the stream bed and increases towards the ridge area. Clear distinction between the sub-soil layers was observed. The first layer being dry graveley soil, followed by a bit moist soil layer having more clay content than the first one, then followed by more consolidated soil layer followed by more compact soil tending towards hard *murum*.

Figure 4-15 – Layers in trial pit

Table 9 - Trial pits - Locations and Depths

Trial pit	Location	Elevation (GPS) (m)	Depth to hard murum layer from surface (feet)
A	18.99183, 73.42792	145	4
B	18.9912, 73.4734	141	2
C	18.99095, 73.47363	146	5
D	18.9906, 73.47303	146	6

Soil permeability / conductivity test

Permeability test is the measure of rate of flow of water through soil. For modelling groundwater flow, it is important to know the conductivity of the soil.

Falling head permeability test (dept of transportation) was carried out in Geotech laboratory of Civil Department, IIT Bombay. For carrying out permeability test, undisturbed soil samples are required. The samples were collected from the trial pits are different depths. The samples were taken with the help of cylindrical sample tubes of known volume. The samples were weighed on the field to calculate density of the sample on field. Then the samples were packed in air-tight plastic bags so as to retain the moisture. The samples in plastic bags were then wrapped in wet gunny bags and brought to IIT Bombay.

In the laboratory, the samples were weighed again to check whether there are any changes in density. After verifying the density, the sample was reconstituted according to the field density (bulk density i.e. soil + water density) which was then fitted in the permeameter apparatus. Then water was allowed to flow through the sample for calculating the coefficient of permeability by using following equation –

$$K = 2.3\ (aL/At)\ log_{10}(h1/h2)$$

Where:

- $K = coefficient\ of\ permeability$
- $a =$

  $cross - sectional\ area\ of\ the\ standpipe$ – $295.63\ sq\ mm\ (19.4\ mm\ dia)$
- $L = average\ height\ of\ the\ sample\ for\ the\ load\ increment$ – $6\ cm$
- $A = cross - sectional\ area\ of\ the\ sample$ – $50\ sq\ cm$
- $t = elapsed\ time\ increment$
- $h1 = height\ of\ water\ at\ the\ beginning\ of\ time\ increment\ in\ mm$
- $h2 = height\ of\ water\ at\ the\ end\ of\ time\ increment\ in\ mm$

The samples taken and their readings are as follows –

One sample from every pit was tested:

- $A/4A$ – $Sample\ from\ 4\ feet\ down\ in\ pit\ A$
- $B/2B$ – $Sample\ from\ 2\ feet\ down\ in\ pit\ B$
- $C/1C$ – $Sample\ from\ 1\ feet\ down\ in\ pit\ C$
- $D/0D$ – $Top\ soil\ sample\ from\ pit\ D$

Table 10 - Permeability calculation

Sample	Constant (2.3*aL/A) (cm)	Initial Head h1 (cm)	Final head h2 (cm)	Log10 (h1/h2)	Time (sec)	K (cm/sec)	K (m/d)
A/4A	0.8158	90	89	0.004853	780	5.08E-06	0.004385
A/4A	0.8158	86	85	0.00508	900	4.6E-06	0.003978
A/4A	0.8158	85	78	0.037324	6420	4.74E-06	0.004098
A/4A	0.8158	78	36.6	0.328614	84060	3.19E-06	0.002755
A/4A							0.003804
B/2B	0.8158	103	93	0.044354	135	0.000268	0.231579
B/2B	0.8158	88	78	0.052388	169	0.000253	0.218496
B/2B	0.8158	68	58	0.069081	295	0.000191	0.165057
B/2B							0.205044
C/1C	0.8158	93	83	0.049405	81	0.000498	0.429914
C/1C	0.8158	83	73	0.055755	95	0.000479	0.413675
C/1C	0.8158	68	58	0.069081	120	0.00047	0.405765
C/1C	0.8158	48	38	0.101458	177	0.000468	0.404026
C/1C							0.413345
D/0D	0.8158	93	83	0.049405	16	0.002519	2.176442
D/0D	0.8158	78	68	0.059586	24	0.002025	1.74996
D/0D	0.8158	63	53	0.075065	30	0.002041	1.763648
D/0D	0.8158	48	38	0.101458	45	0.001839	1.589168
D/0D							1.819804

It is clear from the analysis that the conductivity of the soil decreases with the depth of the soil layer. The conductivity of the soil sample taken from deep in the pit is close to the conductivity of weathered basalt (ref.) while the conductivity of the soil sample taken from top soil indicates that the soil is sandy loam (ref.- conductivity of sandy loam ranges from 0.1 to 10 m/d).

Lesson learnt

Given the availability of labour and time, only four trial pits were dug. It was then understood that the number of trial pits dug was less and did not cover the whole watershed. More pits at regular intervals were needed to be taken for correct analysis of conductivity of the soils. As only one sample per pit was taken, the accuracy of the analysis can be doubted.

4.3.3 Geological data

Rock characteristics are as important (or even more so) as soil characteristics for modelling groundwater flow in a watershed. It is known that Western Ghats region is all underlain by igneous hard rock, basalt. Basalt is known for its low conductivity and specific yield and hence very low groundwater storage is possible in basalt region.

The primary porosity in case of basalt though very low, the secondary porosity (which is due to cracks, fractures or fissures in the rock) can be sometimes high. The cracks or fractures work as conduits or channels for groundwater flow. Also, apart from pure basalt (known as compact basalt), there are other varieties of basalt like weathered basalt, vesicular basalt, vesicular amygdaloidal basalt etc. which have varying conductivity and storativity values. Hence, proper knowledge of the underlying rock is needed for any type of watershed intervention.

A preliminary survey of the watershed was done just to know about the geology by looking at stream bed, rock outcrops and outlet of watershed. A rough picture of the underlying rock was predicted based on the survey and the observations in the trial pits. The top soil layer was followed by weathered basalt with transitory hard murum layer. This weathered basalt was around 2-3 m thick as observed on the walls of the well. No vesicules were seen in the rock. This layer was followed by a compact basalt layer which could be several meters thick. There were few outcrops of compact basalt in the stream bed as well. The rough picture predicted is as follows

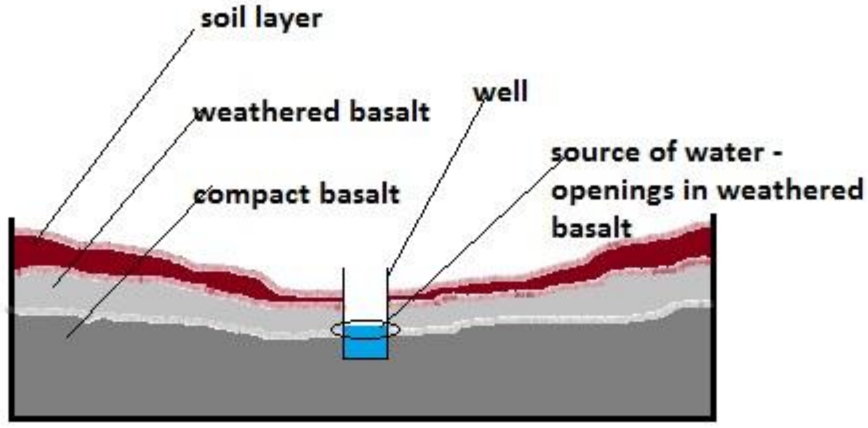


Figure 4-16 – Conceptual model of geological layers through rapid geological survey

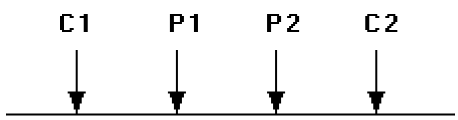
But in order to have more exact information about the underlying structure, it was decided to carry out Multiple Electrode Resistivity Imaging survey in the watershed.

Multi Electrode Resistivity Imaging survey

MERI (Multiple Electrode Resistivity Imaging) is an advanced technique of traditional electrical resistivity surveys. The basic principle remains the same though. Electrical surveys help in determining the subsurface resistivity distribution by making arrangements on the ground surface. The subsurface resistivity is related to geological parameters like degree of water saturation / presence of water in the rock, its porosity, mineral content etc.

Traditionally, the resistivity measurements are made by injecting current into the ground through two current electrodes (C1 and C2 in the figure) and measuring resultant voltage difference at two potential electrodes (P1 and P2). From this arrangement, resistivity is calculated as

$p_a = k\ V / I$ - Ohm's Law



This resistivity is "apparent", which is the resistivity of homogeneous ground which will give the same resistance value for same electrode arrangement. But in actuality, the subsurface is not homogeneous block. The "true" resistivity is then calculated by inversion of measured resistivity values using a computer program, which is a complex process.

The four electrodes can be arranged in many ways i.e. spacing between the electrodes can be increased to obtain more information about the deeper sections of the subsurface.

In multi-electrode resistivity imaging, more than four electrodes are used, 48 in this case. The electrodes can be arranged in one line (called 2D survey) or in a grid format (called 3D survey). The equipment has an instrument with a computer which selects all the combinations of four electrodes in particular arrangement and gives the resistivity image of the subsurface.

In case of Mograj watershed, 2D survey (i.e. electrodes in one line) was chosen and the location selected was as below:

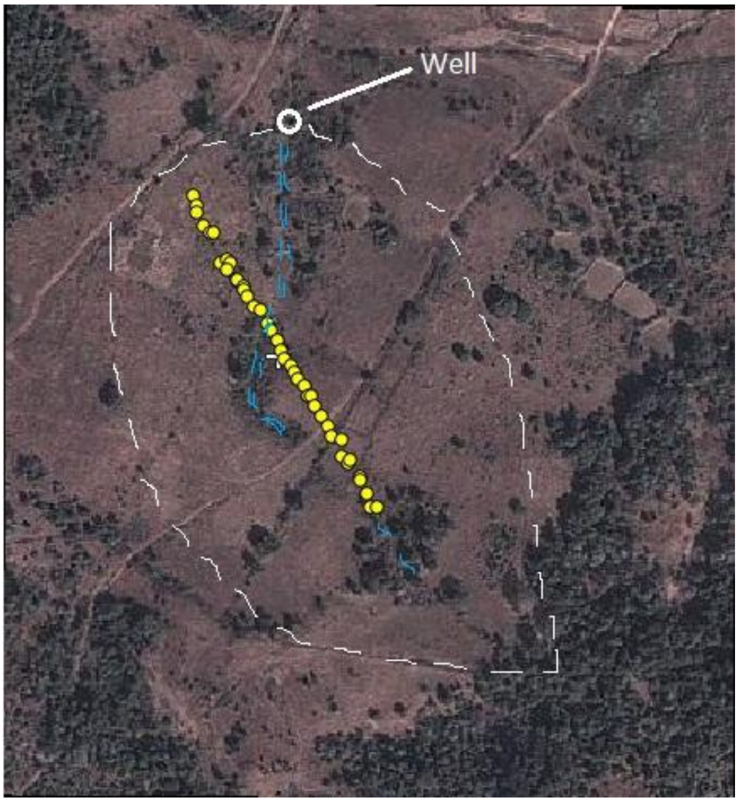


Figure 4-17 – Locations for MERI survey

The locations were decided so that the stream bed and both sides of the stream as well as some part of ridge area are covered. The method is tiresome and involves inserting all the 48 electrodes well inside the soil layer by maintaining distance of 5 m between two consecutive electrodes. Then the computer program starts calculating resistivity which takes around two hours. The results have to be then processed in the laboratory, which takes around two-three days. All this exercise was carried out under the guidance of and with the help of Prof. E. Chandrasekhar and his PhD student Ramesh from Earth Sciences Department of IIT Bombay. The resulting image of the subsurface was as follows:

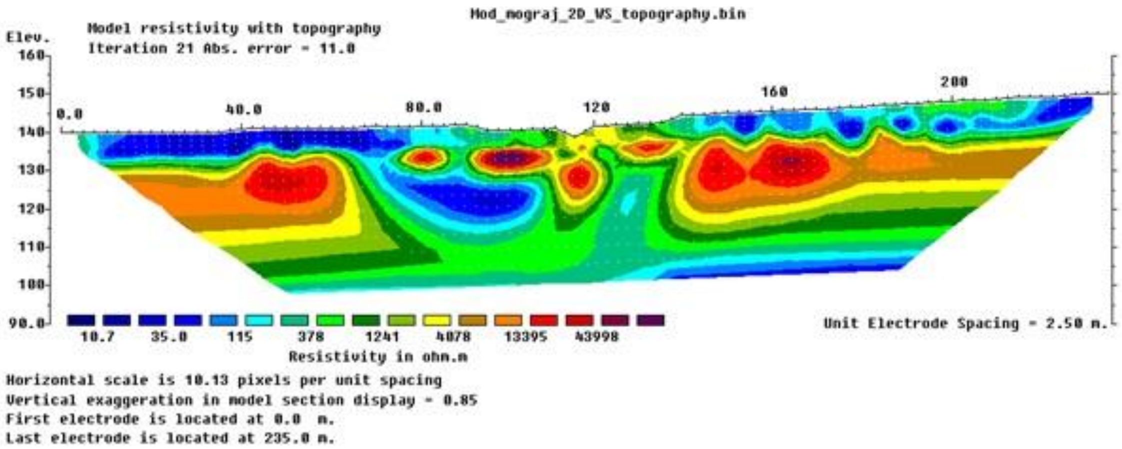


Figure 4-18 – Results of MERI survey

Generally the MERI survey is done on flat surface. But in this case, the 48 points chosen in the watershed had different elevations. The elevations of all the points were entered in the MERI program to get the resulting image.

Interpreting MERI data

To convert the above resistivity picture into a geological picture, some knowledge of typical resistivity values for different types of subsurface materials as well as knowledge about the geology of the area is required. Knowing the geology through rapid geological survey and knowing the resistivity values for common rocks, soils and chemicals (see table), the above image can be interpreted well.

Table 11 - Values of resistivity for different materials

Material	Resistivity (ohm.m)
Igneous and metamorphic rocks	
Granite	$5x10^3 – 10^6$
Basalt	$10^3 – 10^6$
Marble	10^2 - $2.5x10^8$
Sedimentary rocks	
Sandstone	8 - $4x10^3$
Limestone	50 - $4x10^2$
Soils and Waters	
Clay	1 – 100
Alluvium	10 – 800
Groundwater (fresh)	10 – 100
Sea water	0.2

To interpret data from the above image, it is generally assumed that subsurface consists of horizontal layers in which case, the resistivity changes only in depth and not in horizontal direction. Thus, it can be assumed that the changes in resistivity in the image in horizontal direction are due to water saturation in the subsurface while the changes in the vertical direction are due to change in geological formation (i.e. changes in the rock type)

Thus, based on the above assumptions and the rapid geological survey, the presence of compact (highly resistive) basalt is clearly seen on both sides of the stream at around 20m of depth below surface. The brightest blue colour denotes least resistivity which means high conductivity region or even presence of water (if resistivity value less than 100 ohm.m). The regions with dark red / brown colour are regions of very high resistivity which denotes regions with very less porosity and water holding capacity i.e. compact basalt in this case. The regions with blue shades tend towards high conductivity whereas regions with yellow and green shades tend towards low conductivity regions.

Also, the presence of conductive top layer is seen. The depth of this layer is around 10m at the ends and almost zero in the stream bed. This layer comprises of top soil layer and weathered basalt layer just below it. The moisture content in this layer seems to play an important role. But the green and yellow regions on the right hand side of the stream in the top layer suggest drying of the top soil layer.

The yellow and green regions in the top layer at the centre prove the existence of hard rock in the stream bed. Below this thin hard rock layer there is a blue region around 20m depth from the surface which suggests the presence of confined aquifer which may be supplying the water through spring to the well.

4.3.4 Well water level data

The water level data in the wells in the watershed is very important in modelling the groundwater flows in the watershed. This requires constant monitoring of water levels in the well. For this, a lady in the village, named Tai Agivale, was trained to measure the level of water in the well everyday. She was taught how to handle the measuring tape and take readings at specified time of the day (say morning 6 am).

But due to inability to take readings (due to confusion between feet and meters), inconsistency in timings of the readings and due to time constraints, she was not able to take readings correctly for all days.

Hence, the readings were taken during field visits to Mograj by author and other team members. All the readings were taken between 10am and 12pm. The reading for 1st Oct 2012 was taken as per the discussions with the people.

Table 12 - Well water level data

Date	**Depth to water level (m)**	**Water table (m) above mean sea level (Elevation of well = 135.9 m)**
01-10-2012	1	134.9
13-01-2013	1.5	134.4
27-01-2013	2	133.9
16-02-2013	3.4	132.5
30-03-2013	4.9	131
03-04-2013	5.1	130.8
11-04-2013	6.1	129.8
24-04-2013	7.1	128.8
02-05-2013	7.5	128.4

4.3.5 Rainfall data

The rainfall data for last five years was acquired from Karjat Taluka Office.

Table 13 - Karjat rainfall data

Year	Average Rainfall (mm / year)
2006-07	4765
2007-08	3998
2008-09	3489
2009-10	2749
2010-11	4400
Average	**3880.2**

4.3.6 Outcome

Based on the information acquired from different surveys, it was learnt that there is a thick conductive layer in large parts of the watershed. So, it was thought that the longer this layer retained the rainwater the more it will be the supply to the *varchi* well. For this, the infiltration or recharge rate needs to be increased. One option of doing this is contour trenching. Contour trenching is simple, low-cost method of checking velocity of rainwater runoff. They are pits or trenches dug along the contour line which hold rainwater for longer period of time and improve the local moisture profile.

Thus, contour trenches seemed to be the best option for the present study. Hence it was decided to use GMS (Groundwater Modelling Software) to model the watershed and simulate contour trenches to see the how they impact the *varchi* well.

Chapter 5 – Basics of groundwater modelling

5.1 Groundwater flow physics

5.1.1 Continuity equation of groundwater flow

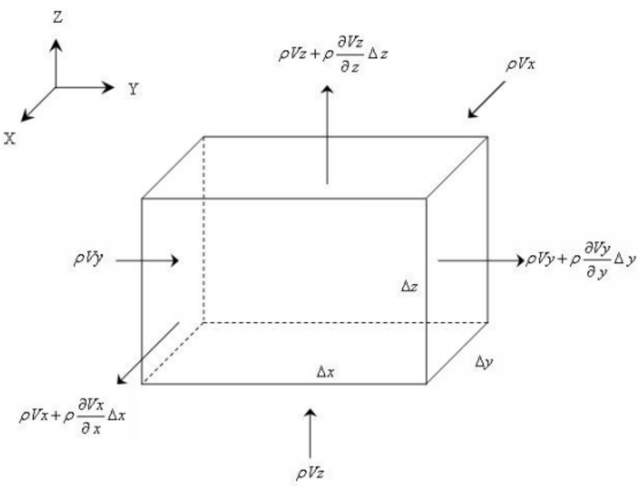


Figure 5-1 – Continuity equation of groundwater flow

Consider the flow of ground water taking place within a small cube (of lengths Δx, Δy and Δz respectively the direction of the three areas) in a saturated zone where ρ is the density of water and V_x, V_y, V_z are the velocity components of water in *x*, *y* and *z* directions.

The total incoming water in the cuboidal volume should be equal to that going out. Thus, defining inflows and outflows as:

Inflows:

- In x-direction: $\rho v_x (\Delta y. \Delta z)$
- In y-direction: $\rho v_y (\Delta x. \Delta z)$
- In z-direction: $\rho v_z (\Delta x. \Delta y)$

Outflows:

- In X-direction: $\rho \left(v_x + \frac{\partial v_x}{v_x} \Delta x \right) (\Delta y. \Delta z)$
- In Y-direction: $\rho \left(v_y + \frac{\partial v_y}{v_y} \Delta y \right) (\Delta x. \Delta y)$
- In Z-direction: $\rho \left(v_z + \frac{\partial v_z}{v_z} \Delta z \right) (\Delta x. \Delta y)$

Thus, the net mass flow per unit time through the cube works out to:

$$\left[\frac{\partial v_x}{v_x} + \frac{\partial v_y}{v_y} + \frac{\partial v_z}{v_z}\right] (\Delta x. \Delta y. \Delta z)$$

The conservation principle now requires that sum of the three quantities be zero. Thus,

$$\frac{\partial v_x}{v_x} + \frac{\partial v_y}{v_y} + \frac{\partial v_z}{v_z} = 0$$

This is referred to as the equation of continuity in groundwater flow.

5.1.2 Darcy's Law

The water flow just observed during the derivation of continuity equation is due to the difference in hydraulic / potentiometric head per unit length in the direction of flow. Henry Darcy, a French engineer was the first to suggest and derive a relation between the velocity as seen in the continuity equation and the hydraulic gradient.

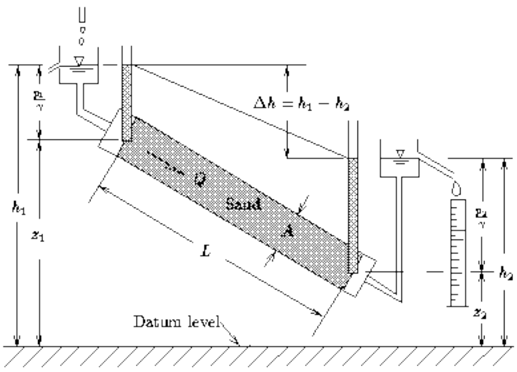


Figure 5-2 – Darcy's Law

According to his experiments, the discharge Q passing through a tube of cross-sectional area A filled with a porous material is directly proportional to the difference of hydraulic head h between the two end points and inversely proportional to the flow length L.

Thus, $Q \propto A . \frac{h_1 - h_2}{L}$

He introduced the proportionality constant K *i.e. hydraulic conductivity* of the porous material, which finally makes the equation as,

$$Q = -KA\frac{dh}{dL}$$

- Negative sign is introduced because the hydraulic head decreases in the direction of flow
- $\frac{dh}{dL}$ is known as the hydraulic gradient

- Dividing Q by, we get specific discharge, denoted by v, or the velocity of the fluid flow;

$$v = \frac{Q}{A} = -K\,\frac{dh}{dL}$$

- It may be noted that this velocity v is not quite the same as velocity of fluid flowing through an open pipe, because it is defined as the total discharge per unit area of soil mass, not as the total discharge per unit area of pore space.
- Primarily, Darcy's Law holds was devised for saturated porous medium of soil. But it has been proved by Buckingham (1907) and Childs and Collis-George (1950) that Darcy's Law also holds true for unsaturated soils though with varying magnitudes of coefficient of permeability (K above) for different volumetric water contents (Fredlund D. G. Soild mechanics for unsaturated soils).

5.1.3 Basic differential equation of groundwater flow

Substituting Darcy's Law in the equation of continuity we get,

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right) = 0$$

Here, hydraulic conductivities in the three directions are assumed to be different i.e. for anisotropic medium. If isotropic medium with constant hydraulic conductivity in all directions is considered, the equation becomes,

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0$$

This equation, also known as Laplace's equation (appears in many places in mathematical physics) is known as the basic equation governing the groundwater flow. The basic problem in all the groundwater models is to find the solution to this Laplace's equation.

As the conservation principle has been applied for deriving this equation, it means that no mass is gained or lost or there is no net inward flux or outward flux to or from this system. Thus, this equation is for the steady incompressible groundwater flow where heads don't change with time.

Now, if the heads change with time, the conservation principle cannot be applied. Hence, some mass will be gained or lost with time depending upon the heads. So there will be change in volumetric water content of the material. The net water stored depends on specific storage which is defined as,

$$S_s = \rho g(\alpha + n\beta)$$

Where ρ is the density of water, α is the compressibility of material, n is the porosity of the material and β is the compressibility of water. The groundwater flow equation now becomes,

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) - W = \frac{S_s}{K}\frac{\partial h}{\partial t} \quad \ldots\ldots\ldots (1)$$

where W is the volumetric flux per unit volume. The above equation is the standard equation for transient flow or flow under non-equilibrium conditions, for heterogeneous and anisotropic porous material, where heads change with time.

Groundwater flow modelling is basically solving this equation for water table heads in a given region / aquifer, with given initial and boundary conditions along with external parameters like rain, lake river etc. The most popular groundwater flow equation solver is MODFLOW developed by United States Geological Survey (USGS) which is used in the present study.

GMS (Groundwater Modelling Software) is a 3D visual interface between MOFDLOW and the user, which helps in visualizing the solution given by the equation solver. It is licensed software developed by Aquaveo, an US company and costs around $ 5000. It is widely used groundwater software in developed countries and developing, characterizing and visualizing groundwater models in 3D environment.

In the present study GMS version 7.1 (trial license) with MODFLOW version 2000 are used.

5.2 Finite difference modelling - MODFLOW

MODFLOW is basically a computer program which numerically solves the three-dimensional groundwater flow equation (equation (1) above) for a porous medium by using finite difference method, wherein the continuous system described the equation (1) broken down into finite set of discrete points in space and time, and the partial derivatives are replaced by terms calculated from the differences in head values at these points. This process leads to systems of linear algebraic difference equations whose solution yields values of head at specific points and times. The values obtained are approximates to the time-varying head distribution that would have been given by analytical solution of the partial differential equation of flow (Rumbough, 1995).

Thus, at the heart of MODFLOW lies spatial discretization of an aquifer system with a mesh of blocks called cells, the locations of which are described by rows, columns and layers.

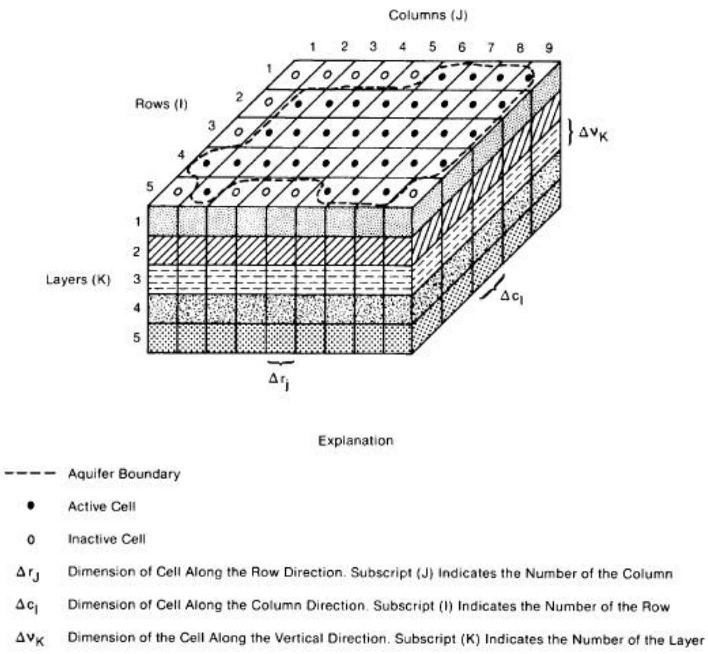


Figure 5-3 - MODFLOW grid

5.2.1 Finite difference equation

The finite difference equation which forms the basis of MODFLOW, is derived by applying the continuity equation seen above i.e. the sum of all flows into and out of the cell must be equal to the rate of change in storage within the cell. Thus, assuming density of water as constant again, the continuity equation for the balance of flow in a cell will be,

$$\sum Q_i = S_s \frac{\Delta h}{\Delta t} \Delta V$$

- Q_i is the flow rate into the cell
- S_s is the specific storage; volume of water which can be injected per unit volume of aquifer material per unit of change in head
- ΔV is the volume of the cell and
- Δh is the change in head over a time interval Δt

Now if a particular cell *i, j, k* is considered along with its six adjacent cells *i-1, j, k; i+1, j, k; i, j-1, k; i, j+1, k; i, j, k-1; and i, j, k+1,* the volumetric water discharge between through six faces of the cell can be obtained by applying Darcy's law.

E.g. flow into the cell *i, j, k* in the horizontal direction from the cell *i, j-1, k* would be,

$$q_{i,j-1,k} = K_{i,j-1,k} \,.\, \Delta c_i \Delta v_k \,.\, \frac{h_{i,j-1,k} - h_{i,j,k}}{\Delta r_j}$$

- $h_{i,j-1,k}$ and $h_{i,j,k}$ are heads at respective nodes, $K_{i,j-1,k}$ is the hydraulic conductivity along the row between the two cells, $\Delta c_i \Delta v_k$ is the area of the cell face normal to the flow direction and Δr_j is the distance between the cells.

Similar equations can be written for the flow into the cell from remaining five faces. In addition, the flows into the cell from features or processes external to the aquifer, such as areal recharge, evapotranspiration, streams, drains or wells, additional terms are also to be considered. These flows may be dependent on the head in the receiving cell but independent of all other heads in the aquifer, or they may be entirely independent of head in the receiving cell. After considering all the flows and expressing the time derivative of head in terms of specific heads and times, the finite difference approximation for the cell i, j, k is obtained from the continuity equation

$$flow\ from\ six\ faces\ into\ cell\ i,j,k +$$

$$external\ flows\ into\ or\ out\ of\ i,j,k$$

$$= S_{s_{i,j,k}} \left(\Delta r_j \Delta c_i \Delta v_k\right) \frac{h_{i,j,k}^{m} - h_{i,j,k}^{m-1}}{t_m - t_{m-1}}$$

- $t_m - t_{m-1}$is time interval and $h_{i,j,k}^{m}$ and $h_{i,j,k}^{m-1}$are heads at respective time intervals. Time derivative of head is approximated using change in head at the node over time interval which precedes the time at which the flow is calculated. This is termed as backward difference approach.

This equation is the basis for the simulation of partial differential equation of groundwater flow. The equation has seven heads, six for the six adjacent cells and one for the same cell from previous time step. These seven heads are unknown at the end of time step t_m. Thus, the equation cannot be solved independently. However, an equation of this type can be written for each active cell in the mesh; and, since there is only one unknown head for each cell, we are left with a system of "n" equations in "n" unknowns. Such a system can be solved simultaneously (Rumbough, 1995).

For the simulation to start, two types of inputs are necessary:

Initial head distribution – The initial head distribution provides a value of $h_{i,j,k}^{1}$at each point in the mesh i.e. it provides the values of head at the beginning of the first of the discrete time steps into which time axis is divided in finite-difference process. The first step is to find solution for $h_{i,j,k}^{2}$which marks the end of first step and so on.

Boundary conditions – The groundwater flow equation is solved by solving the boundary value problem. Boundary value problem is a differential equation with additional constraints, called boundary conditions. In MODFLOW, the boundary conditions can be set at the beginning, by entering the status of certain cells in the mesh in advance. There are three kinds of boundary conditions:

- **Known head or constant head** – the head for some cells is specified in advance, and this head remains constant throughout the simulation
- **Known flow** – the flow into or out of particular cell is known beforehand e.g. withdrawal of water from well per day
- **No flow** – These are the cells for which no flow into or out of the cell is permitted, in any time step in the simulation

5.2.2 Iterative method

Each time step in the simulation in MODFLOW starts by arbitrarily assigning a trial value or estimate for the head at each cell at the end of that step. A procedure for calculation is then started which alters these estimated values, producing a new set of head values which are in closer agreement with the system of equations. These new, or interim, head values then take the place of the initially assumed heads, and the procedure of calculation is repeated, producing a third set of head values. This procedure is repeated successively, at each stage producing a new set of interim heads which more nearly satisfies the system of equations. Each repetition of the calculation is termed as **iteration**. Finally the changes made by the succeeding stages become very small, and this smallness is utilized in determining when to stop the iteration also termed as closure criterion or convergence criterion.

Thus, during a MODFLOW simulation, series of iterations form one time step, series of time steps form one stress period and user can enter multiple stress periods each with specific stress data like monsoon period data, post-monsoon period data etc (Rumbough, 1995).

5.2.3 Packages

The modular structure of MODFLOW consists of a Main program and a series of highly independent sub-routines called modules. The modules are in turn grouped into packages. Each package deals with the specific feature of hydrologic system which is to be simulated, such as simulation of a well, simulation of a lake, simulation of an underground barrier structure, simulation of stream, simulation of drains, rains etc. (Rumbough, 1995)

Chapter 6 - Modelling Mograj watershed

6.1 Methodology

The main attributes / parameters necessary to model a groundwater system are –

- Aquifer boundaries – with regards to horizontal extent as well as depth
- Aquifer characteristics – conductivity, specific yield, storage etc.
- Boundary conditions i.e. no flow boundary, observed heads, observed flow into or out of the system i.e. infiltration of rain water during rainy season, flow of water out of the system through aquifer outlet, water withdrawn from the aquifer through wells etc.

It is assumed that aquifer boundaries in this case match with the watershed boundaries. That this assumption is reasonable was verified through field inspection.

Primary as well as secondary data collected so far will be incorporated in to GMS to form a groundwater system. The shallow unconfined aquifer will comprise of top soil and weathered basalt layer which goes 2 to 15 m deep under the surface, below which the compact basalt aquifer starts. The terrain data is taken from Google Maps Elevation API after correction from ground truthing. The depths of 1st layer are taken from soil and MERI surveys. The conductivity values are taken from permeability tests and literature data. The water withdrawal data from well is taken from primary data survey. The observed heads for the well are also taken from field. The recharge rate is calculated from rainfall data and runoff coefficient for Western Ghats region (Inglis).

The model was developed based on above data. The rainfall in the region is very high. Hence it is assumed that it will be raining continuously during the rainy season. Hence there is a fixed amount of water entering into the system and same quantity flowing out. This situation will be modelled by a steady state simulation.

Steady state solution will give the water table heads just after the end of rains i.e. the groundwater table situation on 1st October. Now, at this point of time the recharge through rainfall in the model will be stopped and the model will be allowed to run for the next 250 days i.e. till June 7thof next year, the start of next rainy season. Thus, there will be two stress periods (first, steady state period, followed by transient state period of 250 days). The initial heads for the transient state will be taken automatically from the calculated heads at the end of steady state.

During transient state there will be no external water entering the system. The water already stored in the system at the end of rainy season will flow out through watershed boundary according to the storage and yield of the aquifers and other boundary conditions. The water table heads at the end of this period should reflect the condition on the field. This will validate the model.

After validating the model, staggered contour trenches will be simulated and incorporated in the model and the model will be run again in steady as well as transient states to verify the impact of contour trenches on groundwater storage and water table heads at various points and at different points of time.

6.2 Assumptions and constraints

- All the layers were considered as perfectly homogeneous and isotropic in nature, i.e. having conductivity values did not change in any direction and are same at all points in specified zone / aquifer. But in reality, such ideal aquifers don't exist.
- Conductivity zones were marked based on the interpretation of results of resistivity survey and geological survey and few observation points in the watershed.
- Depth of compact basalt layer was assumed to be 15 m
- During the simulation, if the saturated thickness i.e. the water column in the cell becomes zero i.e. the head goes below the bottom elevation of the layer, MODFLOW converts that cell into "dry cell" and makes it permanently inactive. In this case, the top layer cell will be shown as dry while bottom layer cell below it will be shown as flooded which seems absurd. The solution to this is cell rewetting provided in MODFLOW. But after rewetting, MODFLOW can become unstable and can introduce some errors in the calculated heads.

6.3 Preparing the model

6.3.1 Preparing 2D Scatter data for elevations

The points obtained from Google Maps Elevation API are in the form of 3-tuples (latitude, longitude, elevation (m)). In GMS, any point is located by X and Y coordinate and GMS calculates distance between any two points in units of length (i.e. meters, centimetres, feet or inches). Thus, in GMS the latitude and longitude of any point will be simply treated as X and Y coordinates i.e. in terms of distance coordinates. Thus, before importing the Google elevation data to GMS, the latitude-longitude coordinate system must be converted to distance coordinate system. This was done as follows:

Step 1 – The point of minimum latitude and longitude was treated as the origin i.e. $x = 0, y = 0$

Step 2 – Haversine formula (website) was used to calculate the distance between to latitude-longitude pairs. The following distances were calculated -

- Origin and point with max latitude (maximum distance in Y direction, or y_{max})
- Origin and point with max longitude (maximum distance in X direction, or x_{max})

Step 3 – Once x_{max} and y_{max} in terms of distance in meters were obtained, XY coordinates of all the points in between were calculated by doing simple math –

$$x_{any\_pt} = \frac{\left(x_{max} \times \left(long_{any\_pt} - long_{min}\right)\right)}{\left(long_{max} - long_{min}\right)}$$

$$y_{any\_pt} = \frac{\left(y_{max} \times \left(lat_{any\_pt} - lat_{min}\right)\right)}{\left(lat_{max} - lat_{min}\right)}$$

- Where $(long_{max}, lat_{max})$ is the north-east corner point of the elevation grid and $(long_{min}, lat_{min})$ is the south-west corner point (or XY origin) of the elevation grid
- $long_{any\_pt}$ and lat_{any_pt} are longitude and latitude of any point in the grid for which XY coordinates are to be found
- x_{any_pt} and y_{any_pt} are corresponding distances in meters for any point in the grid from the origin.

fx =(J2*(J5-J6))/(A2-J6)

	A	B	C	D	E	F	G	H	I	J
1	Longitude	Latitude	Elevation (m)	Correction from ground truthir	Corrected elevation	X (m)	Y (m)			
2	73.47522	18.99236	136.6135	4.62952	141.242984	287.06	315.83		maxX (m)	287.06
3	73.47504	18.99236	136.4034	4.62952	141.032901	307.3231	315.83		maxY (m)	315.83
4	73.47486	18.99236	136.3061	4.62952	140.935642	330.6641	315.83			
5	73.47467	18.99236	136.2035	4.62952	140.832996	359.4834	315.83		longmax	73.47522
6	73.47449	18.99236	136.1062	4.62952	140.735736	391.8369	315.83		long min	73.47249
7	73.47431	18.99236	136.009	4.62952	140.638477	430.59	315.83			
8	73.47413	18.99236	135.9117	4.62952	140.541217	477.8499	315.83		latmax	18.99236
9	73.47395	18.99236	135.8145	4.62952	140.443973	536.7629	315.83		latmin	18.98952
10	73.47376	18.99236	135.7118	4.62952	140.341312	617.066	315.83			

Figure 6-1 – Lat-long system to X-Y coordinate system

6.3.2 Importing Google image to GMS

The Google image of the watershed and the surrounding region is imported to GMS. To transfer the locations on the image to the GMS coordinate system, GMS 'Register Image' tool is used. If exact locations, in terms of XY coordinate system generated above, for any 2 or 3 points on the image are entered, the tool registers the image and generates corresponding XY values for all the points on the image.

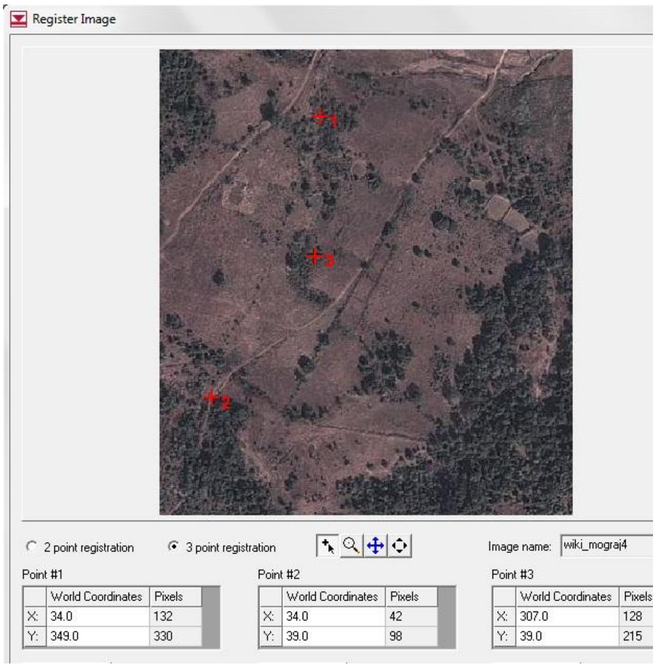


Figure 6-2 – Geo-referencing tool in GMS

This forms the bottom-most layer in GMS over which the conceptual model and 3D grid will be developed for the watershed.

6.3.3 Creating watershed boundary

The elevation data transformed to XY coordinate system is imported to GMS. This data will be stored as Scatter Point dataset in GMS.

The scatter point data is interpolated to 3D grid. IDW (Inverse Distance Weighting) interpolation method (where the values assigned to unknown points are weighted averages of values at known points which are inversely proportional to their distance from the unknown point) is used for interpolating scatter points to form smooth top surface of the grid. The grid dimensions are entered as follows –

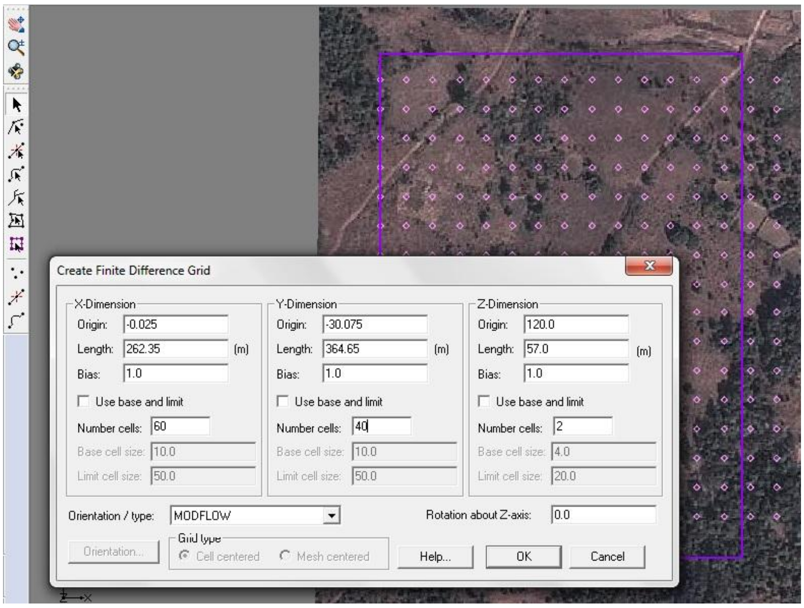


Figure 6-3 – Scatter point data to 3D grid

Next step is to initialize MODFLOW. This can be done by clicking "New MODFLOW" under grid menu. This will initialize all the variables required for simulation.

The contours of the top surface of the grid are generated by using Display Contours option in GMS.

A new conceptual model and a new coverage under it are created. Conceptual model in GMS allows user to create lines, polylines, arcs, polygons etc to represent surfaces, points etc on ground. The conceptual model is just an easier way for the user to create realistic scenarios. During actual MODFLOW simulation, the conceptual model has to be mapped to the underlying grid as MODFLOW only understands the grid, not the conceptual model.

The conceptual model consists of coverages for different representing different properties e.g. one can create a coverage for representing conductivity zones i.e. different zones by drawing polygons or arcs etc. and entering different conductivity values for each zone, or similarly recharge zones etc. So for each property, a coverage can be created under conceptual model. "Boundary" will be the first coverage created in this case. This coverage will be used to delineate watershed boundary by using arcs with the use of generated contours.

Once the watershed boundary is marked, the option "Activate cells in the coverage" will cut all the grid cells lying outside the watershed boundary. Thus, the 3D grid will now perfectly match the boundaries of watershed.

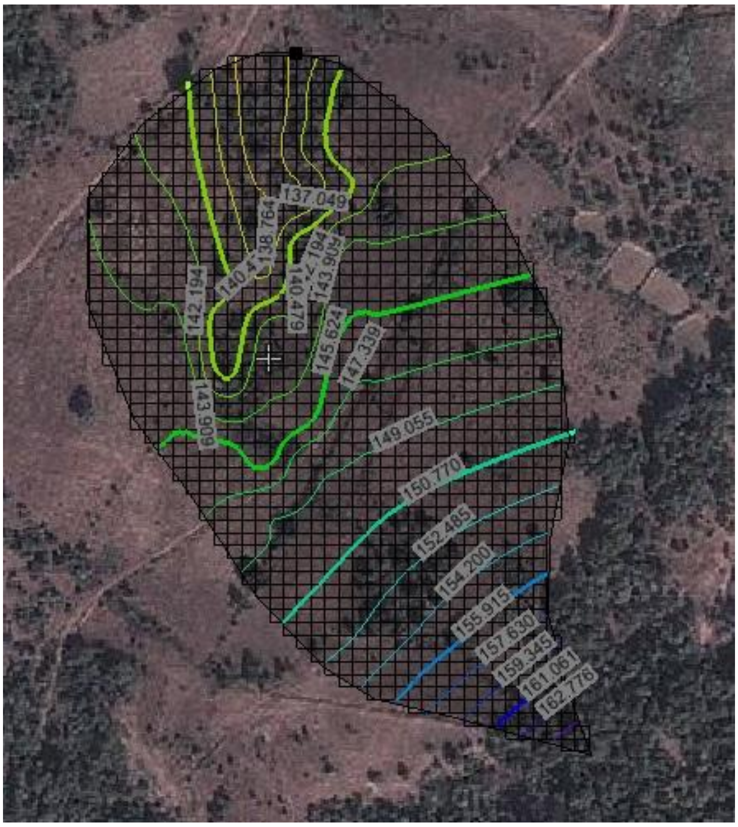


Figure 6-4 – Mograj watershed boundary

6.3.4 Build layers in MODFLOW

The top surface of the topmost layer is already in place. The next step is to set the bottom elevations of the top layer and bottom elevations of the bottom layer.

The elevation data for the bottom of the top layer is available in the form of depths from the ground surface for few observation points in the watershed. Normal process to transport this data to GMS would be to calculate the bottom elevation of all the observation points by subtracting the depths from top elevations and interpolate to bottom elevations of top layer in GMS.

But as the observation points are too few, the interpolation in this case can give unreliable results like bottom elevations being higher than top elevations.

Hence a lengthier but fool-proof method is adopted. The depth values are first interpolated using IDW interpolation method by providing minimum and maximum limits as 0 and 15. This will generate depths for all the points in the watershed. These depths will be subtracted from the top elevations to get bottom elevations of top layer. In this case, there will be no chance of bottom elevation being higher than top elevation as the depth value at no point in the region is negative.

Bottom elevations of bottom layer are obtained by simply subtracting 15 from bottom elevations of top layer for all points i.e. the thickness of the 2nd layer is 15 m throughout the watershed.

6.3.5 Well

A coverage named 'Well' is created under conceptual model by selecting "WEL" package. This allows the user to select a point in the watershed and mark it as a well. The main property of Well package is flow rate i.e. withdrawal rate in cum / day. The withdrawal data can be either constant or transient. If 'constant' is selected the withdrawal data will be fixed for the whole simulation. This option is used for steady state. If 'transient' is selected, withdrawal data at different points of time in simulation can be entered. This option is used for transient state simulation. This is done as follows –

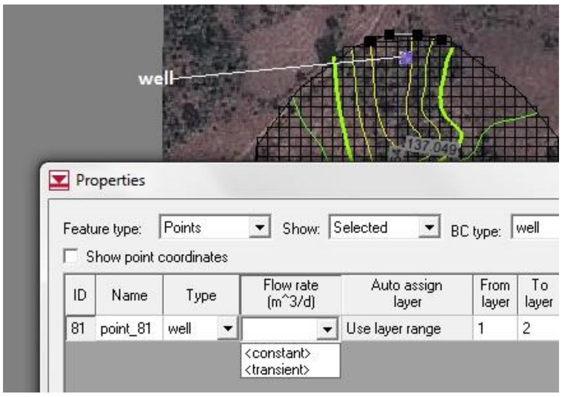


Figure 6-5 – Well package

6.3.6 Recharge

A coverage named "Recharge" is created under conceptual model by selecting "RCH" package. The main property of this coverage is recharge rate in m / day. Determination of recharge rate requires following parameters –

- Rainfall per day in m
- Runoff coefficient (i.e. the percent of rainfall which runs off and does not enter the groundwater system)

The rainfall for the region is taken from table no. 13 above. Runoff coefficient for typical catchment in Western Ghats is calculated according to Inglis and De'Souza formula as follows (CGWB, Manual on artificial recharge of groundwater, 2011) –

$$R = 0.85P - 30.5$$

Where R is runoff per year and P is rainfall quantum per year, and both are expressed in cm.

Thus, for the current watershed *R* comes out to be around 300 cm. Thus, runoff coefficient comes to be around 77%. Thus, if the rainfall during rainy season is 30 mm per day, the runoff will per day will be around 25 mm. Thus recharge will be 5 mm per day or 0.005 m per day.

Thus, the recharge rate of 0.005 m / d is applied to all the cells in the top layer.

6.3.7 Conductivity

As per the interpretation of MERI survey, the top soil layer + weathered basalt layer all over the watershed is a conductive layer. As per the permeability tests, the conductivity of the top soil varies between 0.003 and 1.8 m / d. The conductivity of weathered basalt is generally between 0.03 and 1.72 m / d. The conductivity of the combined layer is taken as mean of the above values i.e. 0.888 m / d. The conductivity of the compact basalt layer was taken as 0.001 m / d.

In the 2nd layer, i.e. compact basalt layer, as per the MERI survey there is a storage / confined aquifer with high conductivity just beneath the stream bed. A conductivity zone representing this confined aquifer is created and given high conductivity of 10 m / d.

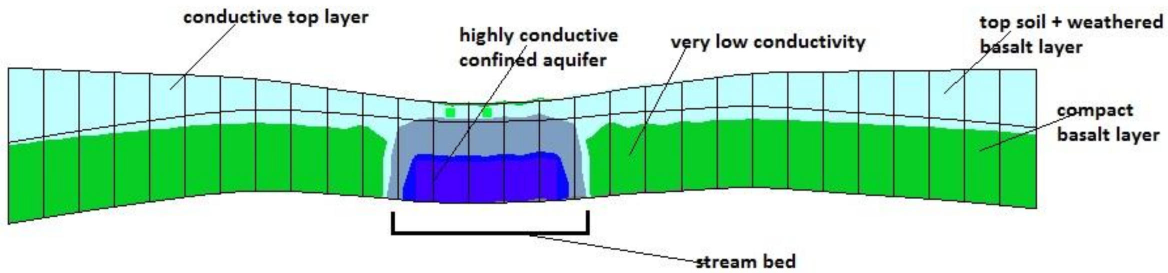


Figure 6-6 – Cross section of layers showing conductivity zones

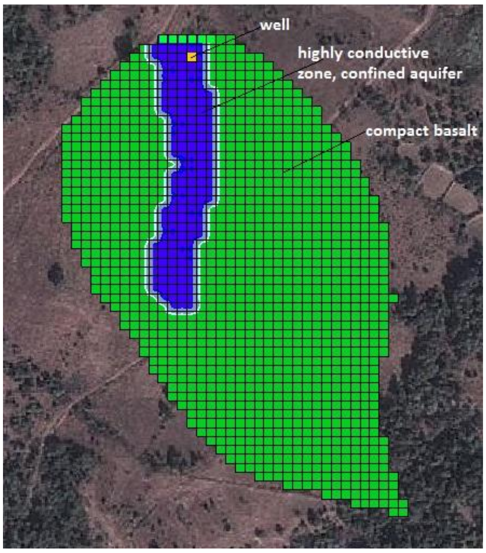


Figure 6-7 – Bottom layer conductivity zones

6.3.8 Drains

In MODFLOW Drain is sort of a boundary condition. During MODFLOW simulation, if the calculated head goes above the elevation of the cell, i.e. above the top surface of the cell, that cell is called flooded cell. This can happen in real life where the water oozes out from subsurface to surface in the form of springs. This generally happens frequently in Western Ghats region where the terrain cuts the base of an aquifer or in low-lying areas.

This water should not be mistaken as rainwater runoff though it eventually gets added to rainwater runoff and flows out of the system. A good indicator for this condition is water logged areas even after the end of rainy season.

During field visits to watershed, it was found out through discussions with the farmers that the immediate two upstream paddy fields in the stream near the well remain water logged for about a month after the rainy season ends. This information will be crucial while validating the model.

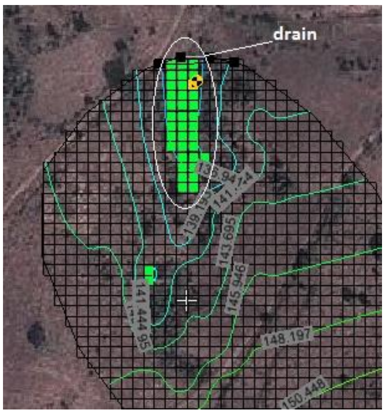


Figure 6-8 – Drain

DRN package of MODFLOW keeps an account of the water which leaves the groundwater system due to heads going above surface elevation. DRN package is activated for the cells covering two paddy fields above the well.

6.3.9 Boundary conditions

No flow boundary – The watershed boundary i.e. the walls of the 3D grid are by default no-flow boundaries i.e. there is no flow of water out of the whole grid.

Constant head boundary – As there is recharge i.e. continuous input of water to the system through rainfall, there should also be an outlet from which the water flows out. This is simulated by a constant-head boundary condition at the stream outlet just downstream of the well. This boundary will represent the channel of groundwater flow out of the system. The value of the constant heads is kept as 135.7 m because it is the observed head near the boundary (at the well to be precise) during the rainy season.

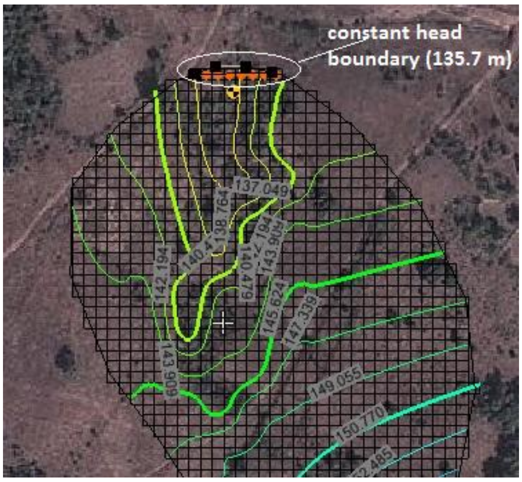


Figure 6-9 – Constant head boundary

This means that the head of 135.7 m is maintained at the boundary of the watershed during the rainy season.

Well withdrawal rate – This is a known-flow condition i.e. the amount of water going out of the system through withdrawal from well. This is already taken care of by creating Well coverage.

6.4 Steady state simulation / Model caliberation

The model with the above parameters and data is run in steady state to match the conditions on the field during or just after rainy season.

If the calculated heads do not match the condition on the field, it means that input data is not correct. Hence model needs to be caliberated by adjusting values of some parameters.

Out of the input variables, well withdrawal data and observed constant heads cannot be changed as they are observed data. The recharge data is also derived from rainfall data which is accurate. The terrain data is also reasonably accurate. Hence the only remaining parameter i.e. conductivity values can be adjusted so as to match model with the conditions on the field.

The conductivity for the top soil + weathered basalt layer was changed to 1.8 m /d after multiple iterations and trials to finally match the field conditions. After this change, the resulting heads matched the heads in the region during rainy season.

6.4.1 Simulation results

The steady state simulation generated water table heads ranging from 135.7 m at the outlet of the watershed to about 155 m in the ridge area. Few cells in the ridge area went dry i.e. the calculated head in these cells went below the bottom elevation for those cells. Also, as seen from the figure below, the top layer is mostly dry in the ridge section of the watershed. This is the situation just after the rainy season. This suggests that there is a potential for some intervention in the ridge area to increase the infiltration and hold water for a longer period of time. This gives a justification for digging contour trenches in the ridge area.

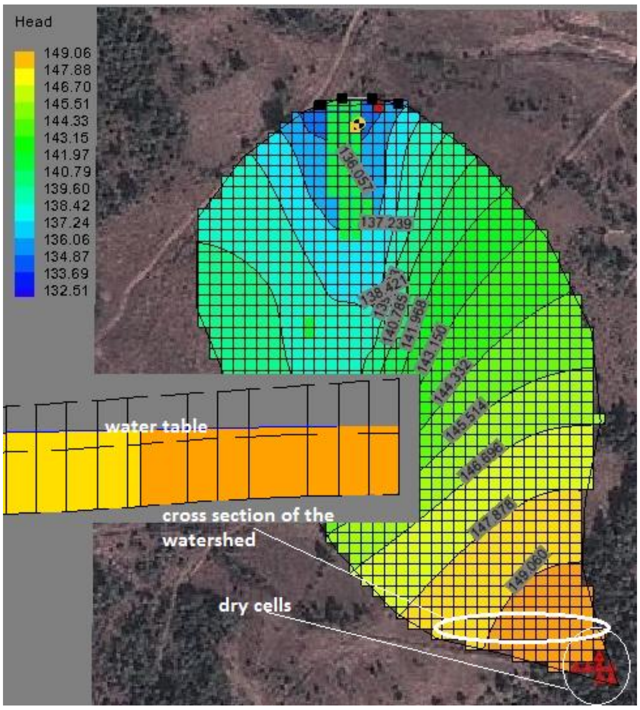


Figure 6-10 – Heads at the end of steady state – dry top layer in ridge area

6.5 Transient state simulation / Model validation

6.5.1 Stress periods

To run the model in transient state, two stress periods are created. The first one is steady state period (the one run above) and the next one is transient state period with length = 250 days and number of time steps = 250 (i.e. heads will be calculated per day).

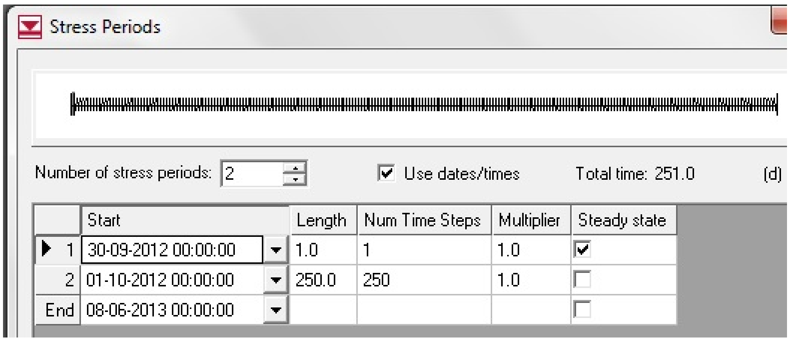


Figure 6-11 – Stress periods for transient state

6.5.2 Drain boundary condition for the transient state

Problem with specified head boundary condition

When the model is run in transient state, the constant head boundary condition cannot be applied because the heads at the boundary will not remain constant / fixed for the complete duration of transient period. The transient state i.e. stress period of length 250 days will be simulated by making by making recharge rate = 0. Thus, there will be no flow of water into the system in transient state. The storage created by the rainfall will go on decreasing resulting in continuous fall in heads at the boundary as well as at all other points in the watershed.

This falling-heads condition at the boundary can be simulated by selecting 'transient' option while specifying constant heads. The heads at the start and at the end of each stress period need to be entered for this option. MODFLOW then calculates intermediate head for each time step and treats it as constant head for that time step.

This is useful when the model is used to validate the on-field conditions. When the model has to be used for prediction of heads (may be to predict results of some intervention in the watershed), the constant-head condition with 'transient' option cannot be used, because the head at the end, or even at the start, of the stress period is not known in that case.

Drain as a boundary condition

Ideally what is required is that the groundwater should be taken out of the system through boundary cells depending on the conductivity of the material and not on the specified heads. Thus, this problem becomes that of seepage through vertical faces of the cells at boundary.

But, calculating the flow out of the cell by means of seepage is not a trivial matter, and is not a straight-forward modelling problem in MODFLOW. Hence, to model this situation, it is imagined that the seepage face is the bottom of the cell and the water seeps out of the system through the contact of the whole grid with the underlying impermeable floor. This can be modelled by using Drain boundary condition (Harbaugh, Michael G and McDonald, 1988).

The main attributes of DRN package are –

- Conductance (sq m / day)
- Elevation (m)

DRN package works as follows –

- During any time step, there will be a calculated head in the DRN cell
- DRN package will remove the water from the cell from the bottom i.e. out of the groundwater system depending on the conductivity of the cell material
- The amount of water leaving will also depend on the head in the cell

Thus, if the bottom elevation of the aquifer at the boundary is specified in the DRN package, during any time step DRN package will simply work as an outlet of the watershed, depending on the conductance specified.

The formula for conductance comes from Darcy's Law –

$$Q = KA\,(\Delta H)\,/\,L$$

- Where K is conductivity of the material in (m/d)
- A is area of cross section of porous medium in (m^2)
- ΔH is the hydraulic gradient
- L is the length of porous medium in (m)
- Q is the discharge in $(m^3\,/\,day)$

In the above formula, the term KA/L is termed as conductance. Thus, Darcy's Law becomes

$$Q = C\,(\Delta H)$$

- Where C is the conductance $(m^2/\,day)$

In the present case, K for the cell is known (i.e. $10m\ /d$); area of cross section will be area of the cell (i.e. 40 m^2), L is known i.e. the thickness of the cell (15 m). Thus C comes out to be around 26 $m^2/\ day$.

The model was then run in steady state by replacing constant head boundary condition by DRN package and by applying the calculated conductance. After multiple iterations and different values of conductance, the model matched for the conductance value of 1 sq m / day. Thus, the caliberated value of conductance is 1 sq m / day, which means that the conductivity of the material which seeps water out of the cell through bottom face is 0.375 m / day.

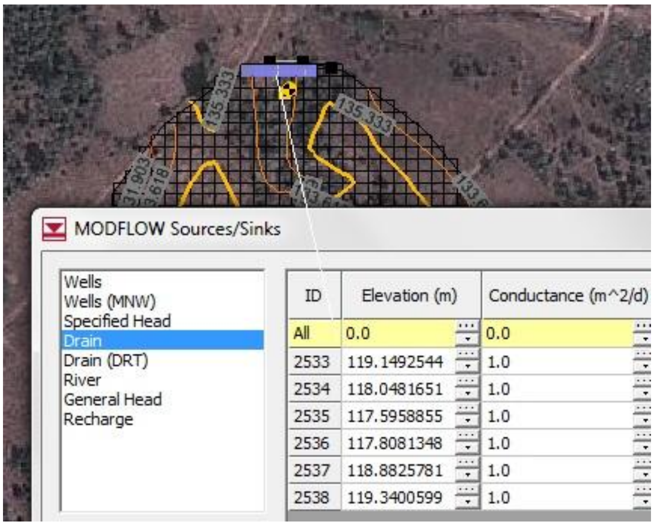


Figure 6-12 – Drain as a boundary condition

This value of conductance was used in transient state simulation.

6.5.3 Well data (withdrawal data, observed heads)

The well withdrawal data is taken as per table no. 7 above.

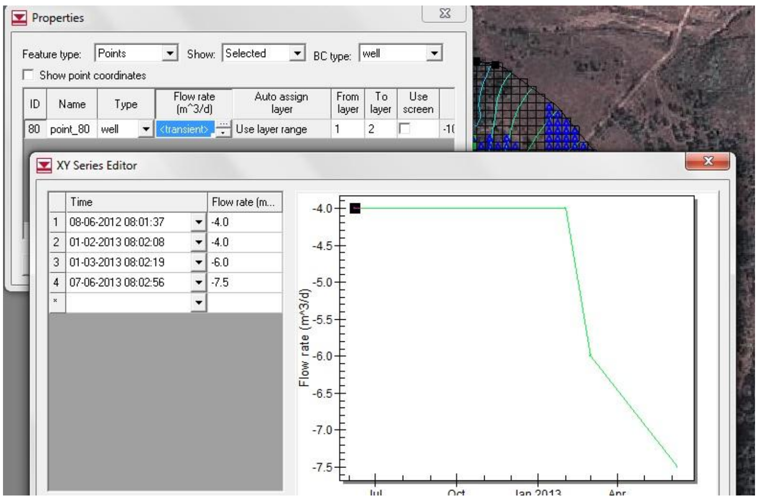


Figure 6-13 – Well withdrawal data

An observation point at the well location was created so as to match the observed heads with the calculated heads at the end of transient state simulation. The observed heads were taken from table no. 12 above.

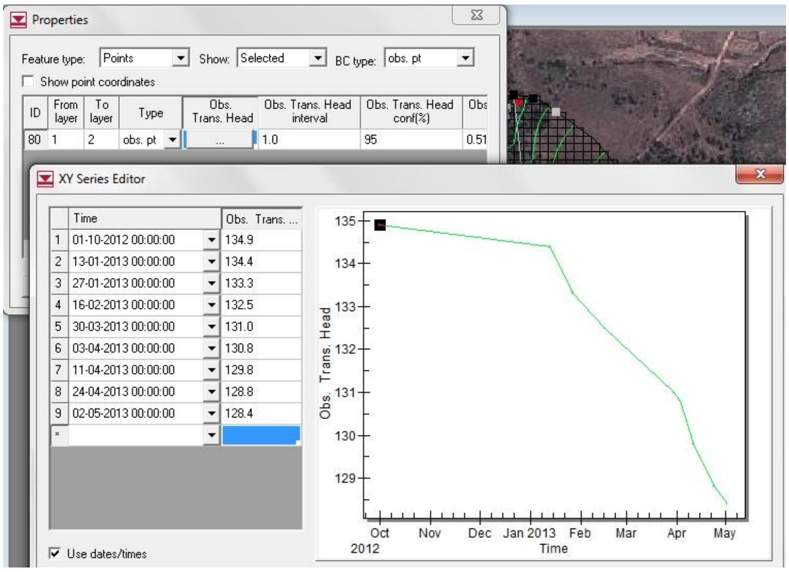


Figure 6-14 – Observed heads

6.5.4 Specific yield and specific storage

Compact basalt has very low specific yield (around 3 to 10%). This value was taken from study done by Deolankar on basalts of Deccan traps. Specific yield for the soil layer sandy loam soil (around 7 to 10%) was taken from USGS.

Figure 6-15 – Specific yield and storage values for layer 1 and layer 2

The specific storage values in case of GMS simulation come into picture only for the 2nd layer i.e. all the layers below top layer. The value is calculated as specific yield divided by the thickness of the aquifer. Thus, specific storage values for both the layers are as follows –

6.5.5 Simulation Results

Heads at different times in transient state

Following are the snapshots of the heads in the watershed at regular time intervals (i.e. on 1st day, 50th day, 100th day, 150th day, 200th day and 250th i.e. last day of the stress period. The red coloured region in the pictures contains dry cells i.e. where the water table has gone down below the bottom elevation of top layer meaning that the top layer is completely dry at that point. Initially the dry region is only in a small portion of the southern ridge area which is the highest part of the watershed. Top layer in this region is very thick (around 10-15 m) and has potential to store / hold more water. But due to high velocity of runoff, the water does not infiltrate much in this region and the result is drying of top layer immediately after the rainy season.

After 8th Jan, even the region near the stream starts drying up. The reason for this is that the top layer becomes very thin in these areas due to hard rock outcrops in and near the stream bed.

After February, almost all the top layer dries up. This is the period when the water levels in the well go below the top layer and the spring giving water to the well becomes clearly visible. The water table in the bottom layer also starts going down fast and eventually the well dries completely around end of April.

(Figure on next page)

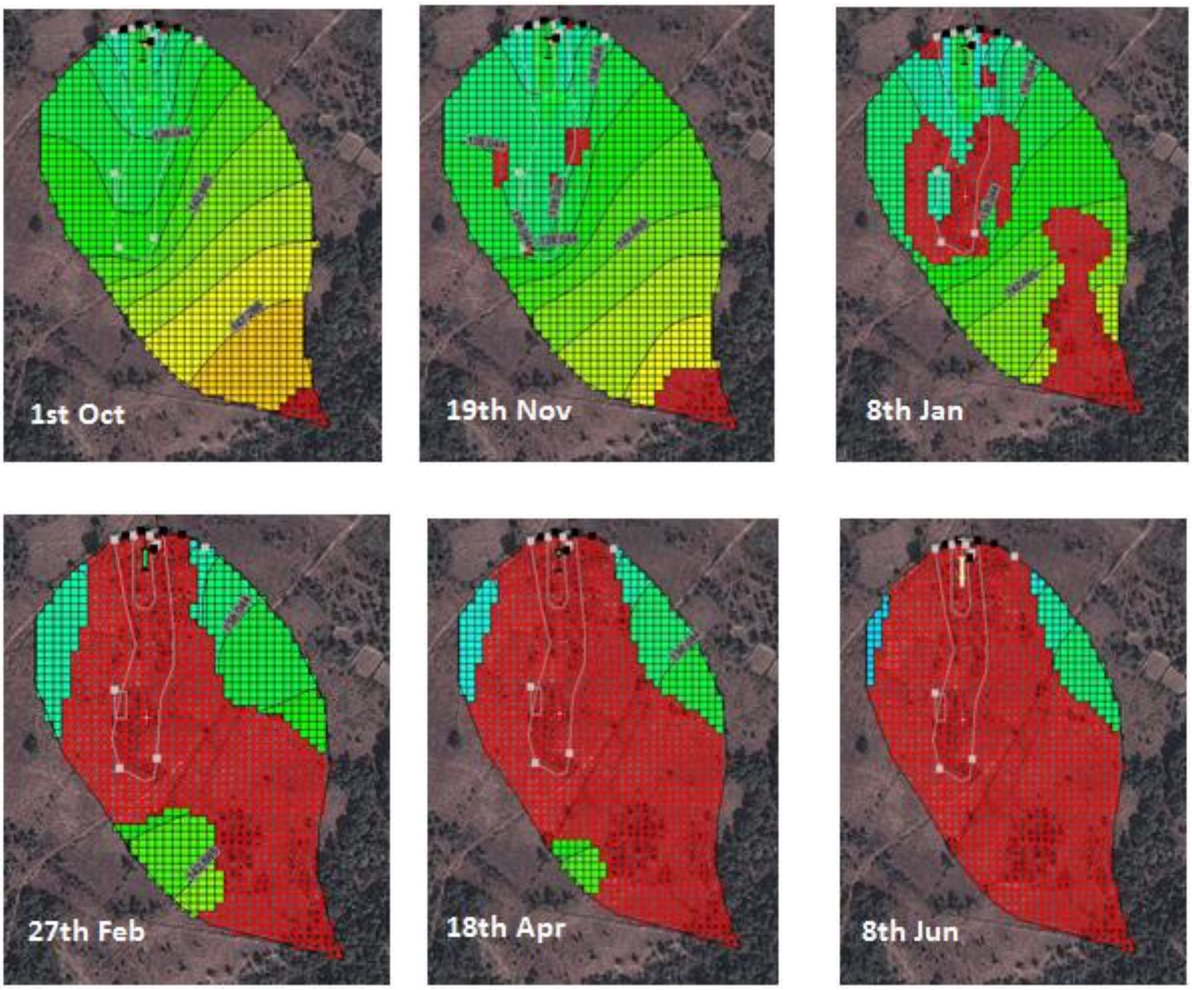


Figure 6-16 – Heads at different times for transient state (without intervention)

Computed Vs. Observed heads

Following is the graph of computed heads at the well observation point. The heads show not much change till December, after which the heads start declining rapidly till the end of stress period i.e. 8^{th} Jun.

The observed heads at the same point are also plotted. The computed heads seem to match the observed heads. The coefficient of determination (R squared) for the observed and computed heads was calculated to see how well the observed heads are replicated by the model. The calculation for R squared is show in figure below. The value ranges between 0 and 1. The more closer it gets to 1 more accurate are the computed values. The value of 0.94 seems reasonable and it can be concluded that the model validates the on-field conditions correctly.

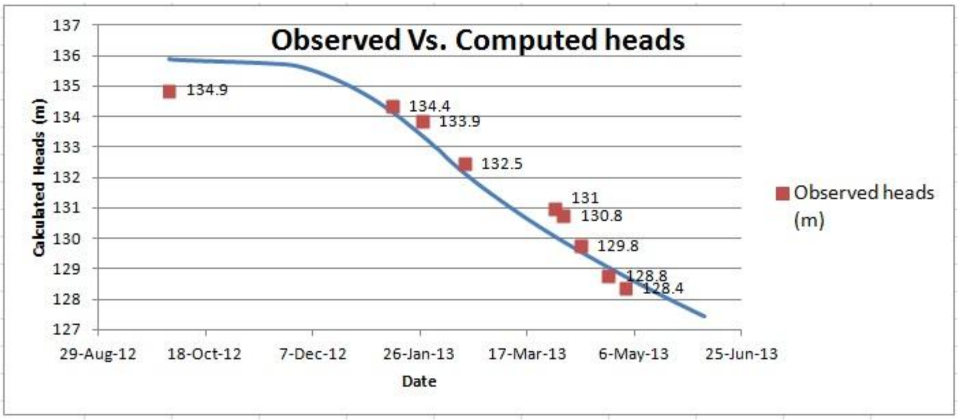


Figure 6-17 – Observed heads Vs. Computed heads

Table 14 - R-squared calculation for computed heads

Date	Observed Heads (m) [A]	Calculated Heads (m) [B]	Error (m) [C] = [A] - [B]	Sum of squares of residuals (sqm) [C]^2	total sum of squares (sqm) ([A] - [M])^2
01-10-2012	134.9	135	-0.1	0.01	10.81679012
13-01-2013	134.4	134.16	0.24	0.0576	7.777901235
27-01-2013	133.9	133.38	0.52	0.2704	5.239012346
16-02-2013	132.5	132.14	0.36	0.1296	0.790123457
30-03-2013	131	130.07	0.93	0.8649	0.37345679
03-04-2013	130.8	129.9	0.9	0.81	0.657901235
11-04-2013	129.8	129.57	0.23	0.0529	3.280123457
24-04-2013	128.8	129.08	-0.28	0.0784	7.902345679
02-05-2013	128.4	128.75	-0.35	0.1225	10.31123457
	mean of observed values (m) [M]			sum [D]	sum [E]
	131.6111111			2.3963	47.14888889
	Rsq = 1 - [D] / [E]	**0.949175897**			

Storage

The flow budget in GMS tells the total quantum of water entering the system and total quantum of water leaving the system at any point of time i.e. for any time step. For the steady state the total water coming into the system is in the form of Recharge i.e. due to rainfall. At the end of steady state the recharge is stopped and the storage created is allowed to flow out of the system through Drain boundary condition as explained above.

The term ‘Storage In’ in the flow budget tells the rate of decrease of storage created by the Recharge. As it can be seen in the following graph, the sudden spike on 1st Oct is due to recharge during steady state. After that, the storage starts decreasing rapidly till December and then decreases steadily till the end. The rapid decrease in the storage is due to high velocity of groundwater runoff from the top layer which is relatively more conductive. Also almost 2/3rd of the storage is lost from the top layer before December. The bottom layer which is less conductive and has less storage space (low specific yield) can store very less water and releases water very slowly. This is the reason, the spring in the well continues till the end though the storage is very less.

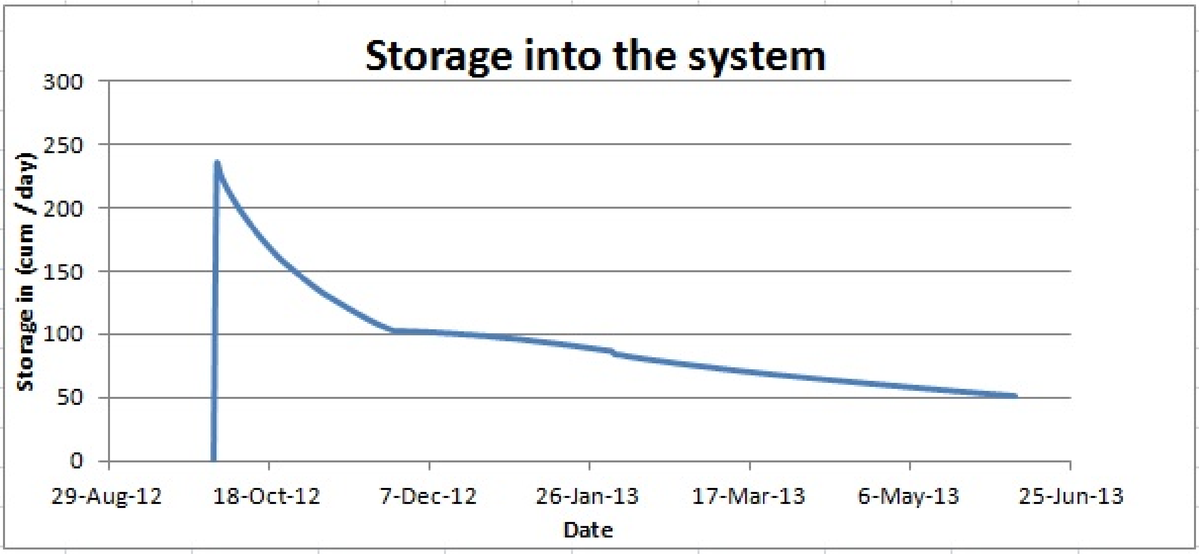


Figure 6-18 – Storage in (without intervention)

6.6 Simulation with intervention

6.6.1 Modelling contour trench

After simulating and validating the model against field conditions, the next step is to run the model with watershed intervention i.e. contour trenches. After putting contour trenches in the model, the model will be run in steady state followed by transient state for the same period (i.e. 250 days) with all the conditions remaining the same. The heads and storage in the watershed will be checked at the end of steady state and transient state to understand the impact of contour trenches.

The important step is to model contour trenches. NREGA Watershed Works Manual gives a fairly straight forward method to calculate amount of rainwater harvested by contour trenches (staggered as well as continuous). The main parameters on which this quantity depends are –

- area of treatment,
- rainfall,
- runoff coefficient,
- dimensions of individual trenches and
- no. of times the contour trench will be filled per day

Once the amount of rain harvested per day (m / d) is calculated, that quantity can be added to recharge rate in the model. With this added recharge the model will thus simulate the impact of contour trenches.

But the main problem with this approach is the parameter ‘number of times the contour trench will be filled per day’. This parameter depends on conductivity of the soil and rainfall quantum per day. As per Watershed Works Manual, in highly conductive soils or high rainfall areas the trench will be filled more number of times per day i.e. 3-4 times, while in low conductivity and low rainfall areas, the trench will be filled less number of times i.e. 1-2 times. But the high rainfall considered in the manual is of the order 700-1000 mm / year. The present study region is very heavy rainfall region i.e. more than 3500 mm / year. In this region, the contour trenches are most likely to remain filled during the whole day. Therefore, the number of times trench is refilled per day becomes irrelevant in this case. Thus, the above method (proposed by the manual) cannot be applied in this case.

The contour trench in this case can be modelled differently, by imagining a small excavation in the watershed (of around x m deep and y sq m in area) which maintains constant head throughout the steady state simulation. The constant head condition will represent the completely and continuously filled trench. This trench will keep on recharging the surrounding area during the rainy season. Thus, there will be more recharge at the end of rainy season than in normal case. This is how the contour trench can be modelled in MODFLOW in very heavy rainfall region.

Thus, total excavation required for all the contour trenches can be calculated and a constant head condition for the excavated region can be simulated in the watershed. The calculation for total excavation required is as follows –

- Total area of recharge zone = 3 ha
- Dimensions of standard staggered contour trench = 2 m (length) x 1 m (width) x 0.5 m (deep)
- Total number of staggered contour trenches that can be dug in one hectare of land = 60-70 (as per information from Taluka Agricultural Office, Karjat and Rural Communes, Narangi)
- Total number of contour trenches to be dug in the watershed = approx 200
- Total excavation required = 200 x (2 x 1 x 0.5) = 200 cum

Thus to simulate contour trenches in the model, the top elevation of cells covering an area of 400 sq m has to be reduced by 0.5 m. This will create total excavation of 200 cum.

As the area of one cell in the present model is approximately 40 m, 10 cells in the recharge area of the model (i.e. ridge area of the watershed) will be selected as contour-trench-cells i.e. their top elevation will be reduced by 0.5 m. Now for putting the constant head condition, the starting heads for these cells will be kept at their original elevation. The cells are selected in a random manner along the contour lines.

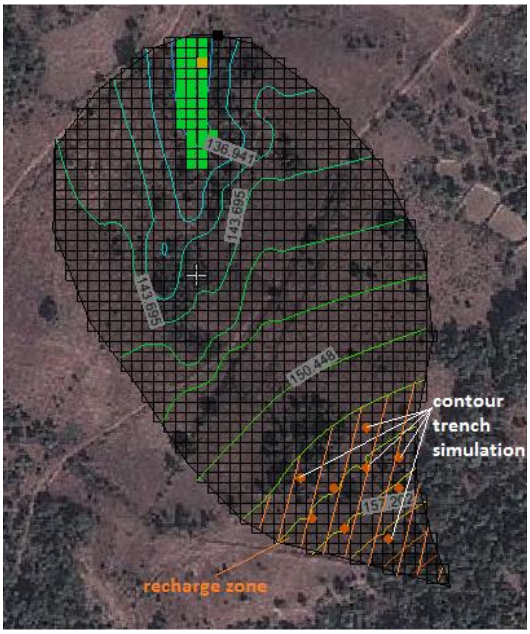


Figure 6-19 – Contour trench simulation

This model is run in the steady state to obtain the new heads due to intervention of contour trenches.

The heads at the end of steady state will be input as starting heads for the next transient state. With these new increased heads, the model will run for 250 days. Thus, impact of the contour trenches on storage and heads at different points will be understood.

6.6.2 Simulation results

Heads at different times in transient state

Following are the snapshots of the heads in the watershed at regular time intervals (i.e. on 1st day, 50th day, 100th day, 150th day, 200th day and 250th i.e. last day of the stress period after contour trench intervention. The pictures show clear change. The blue region in many parts of the watershed denotes that the heads have gone above the top elevations at those points. There is clear rise in heads at all points in the watershed due to increased recharge because of contour trenches. The heads remain pretty high till 8th Jan when some parts of the watershed becoming dry. But the water table starts declining fast from this point onwards as seen from the snapshots of 27th Feb, 18th Apr and 8th Jun. The picture on 8th Jun is not too different than the no-intervention simulation. This means that the contour trenches help in delaying the groundwater runoff by creating more storage. But as the extra storage is over, the heads start declining fast, similar to no-intervention simulation.

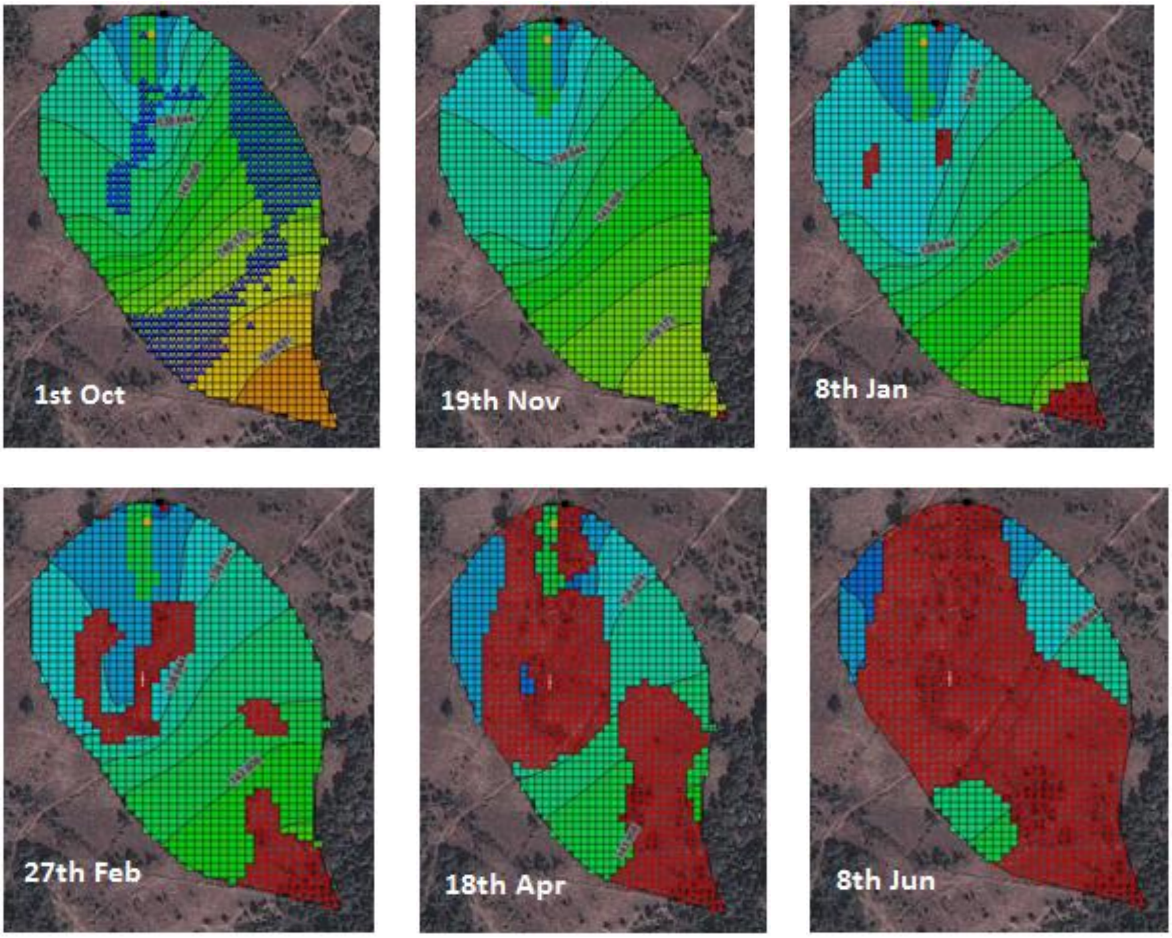


Figure 6-20 – Heads at different times for transient state (with intervention)

Impacts on observation points

Four points in the watershed along with the well observation point were studied for noting the impacts of the intervention on the groundwater flows in the watershed. The four points are as follows –

Table 15 - Observation points in watershed

Point	Elevation (m)	Position
A	159	Highest ridge area i.e. in the south
B	142.1	Point in drain farther from well
C	145.4	Point near to eastern ridge
D	143.2	Point near to western ridge
W (Well)	136.1	Well – In the drain, just close to the outlet of the watershed

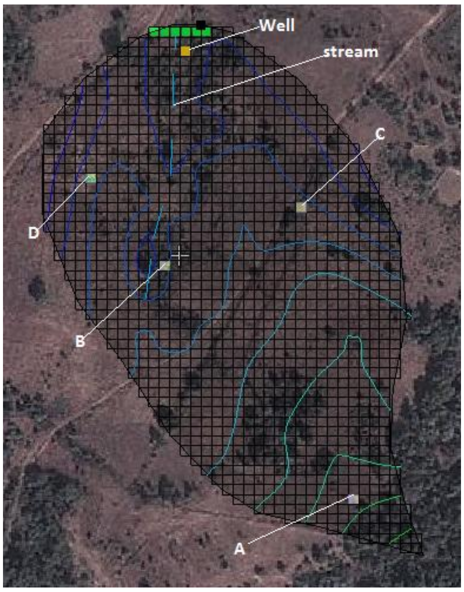
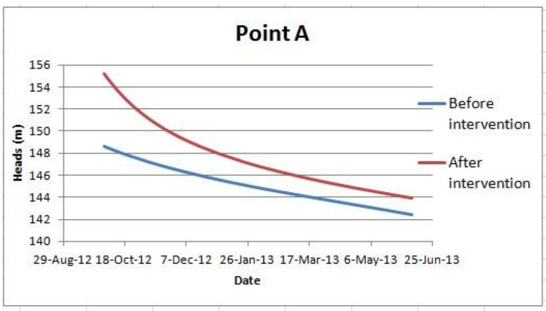


Figure 6-21 – Observation points

Following are the heads at the above selected observation points at all points of time. In general it can be seen that there is increase in heads at all points at the end of stress period. For the point in ridge area where contour trenches are simulated, the heads just at the end of the steady state after intervention are quite high compared to before intervention. This suggests that the contour trenches were successful in retaining water after rainy season. But due to high slopes and less storage, the heads decline fast and get closer to heads before intervention at the end of stress period.

In case of the points close to drainage line, the heads after intervention seem to remain high for a longer period of time. This may be due to the storage zone just underneath the stream bed.

The head at the well observation point at the end of transient state i.e. on 8th Jun has been raised by around 3 m due to the contour trenches. This means that the well will not dry in the summer season.



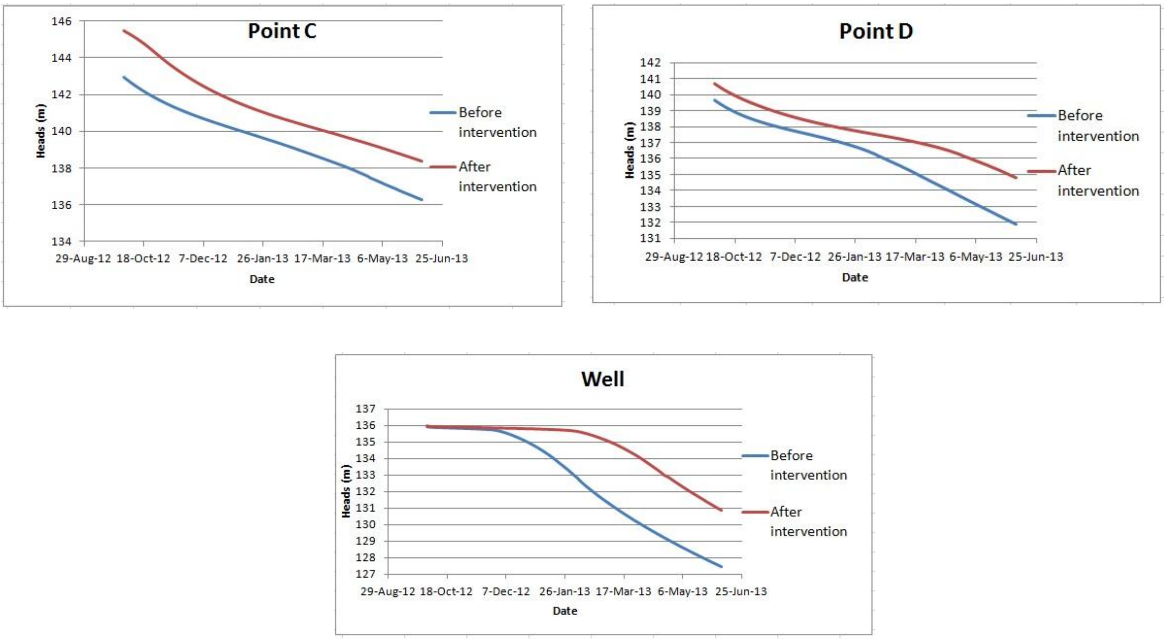


Figure 6-22 – Change in heads at different points – impacts of intervention

Increased Storage

The flow budgets for both the cases show the increase in recharge due to contour trenches. The "Zone 99 to zone 1" value in the figure below indicates the added recharge from the recharge zone.

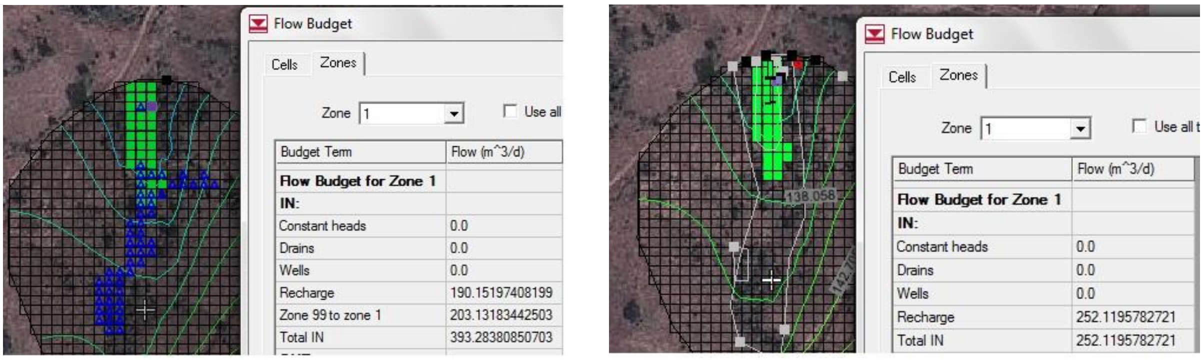


Figure 6-23 – Flow budget at the end of steady state– impact of intervention

The following graph shows the increased storage available just after the steady state. Although the rate of decrease of storage remains the same, the values of storage at the end of the transient state match in both cases.

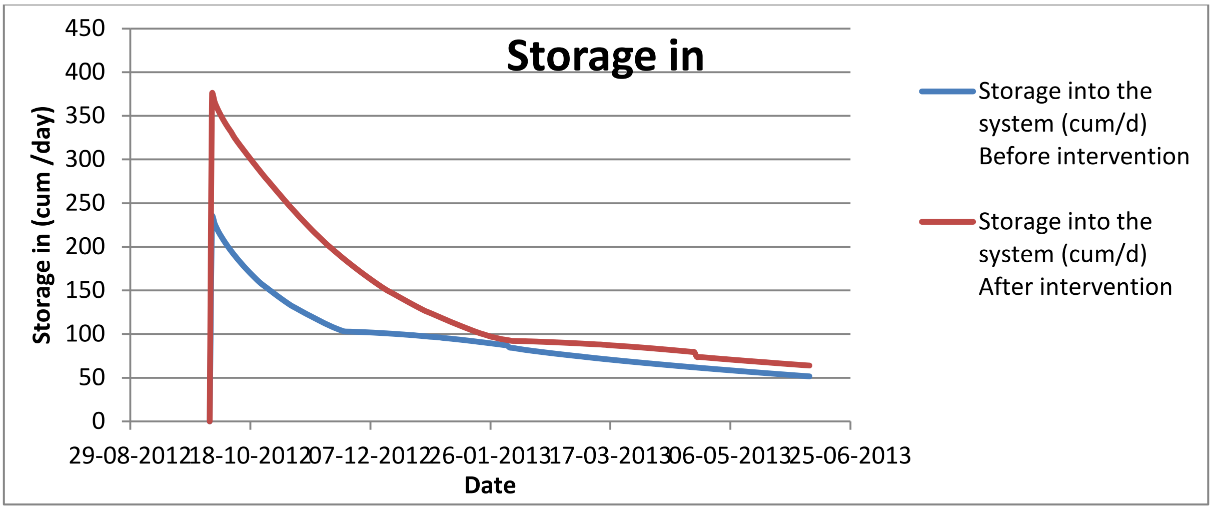


Figure 6-24 – Storage in – impact of intervention

Extra storage created

The value of exact water stored was calculated by summing the volume of water in each cell at different points of time multiplied by the porosity of the rock (considered as 0.03 for compact basalt) for both the cases. Following table shows the amount of extra water in the system after intervention at the end of transient state.

Table 16 - Increase in groundwater storage due to intervention

Before Intervention		After intervention		Increase in groundwater storage due to intervention on 8-Jun-2013 (TCM)
Total volume of water on 1-Oct-2012 (TCM)	Total volume of water on 8-Jun-2013 (TCM)	Total volume of water on 1-Oct-2012 (TCM)	Total volume of water on 8-Jun-2013 (TCM)	
28.67145216	16.90073676	33.33786636	20.73366696	**3.8329302**

Runoff reduction

Based on the recharge at the end of steady state (obtained from flow budget) for both the cases, total reduction in runoff due to intervention was calculated as follows -

Table 17 - Runoff reduction due to intervention

total rainfall (mm/year) [A]	runoff coefficient [B]	total runoff per year (mm) [C] = [A] x [B]	total rainfall per day (mm) [D]	total runoff per day (mm) - [E] = [B] x [D]	recharge rate (mm/day) [F] = [D] - [E]	total area of watershed (sqm) [G]	total recharge in watershed per day (cum) [H] = [G] x [F] / 1000
3880	0.772020619	2995.44	30	24.962	5.038	50000	**251.9**

total recharge per day after intervention (cum) [I]	recharge rate after intervention (mm/day) [J] = [I] / [G] x 1000	total runoff per day after intervention (mm) [K] = [D] - [J]	runoff coefficient after intervention [L] = [K] / [D]	Runoff per year after intervention (mm) [M] = [A] x [L]	Reduction in runoff due to intervention (mm) [N] = [C] - [M]	reduction in runoff (TCM) [O] = [N] x [G] / 1000000
393.34	7.8668	22.1332	0.737773333	2862.560533	132.8794667	**6.643973333**

6.6 Summary of Results

- The Mograj watershed was successfully modelled using GMS and MODFLOW (with given assumptions and constraints). The proposed intervention i.e. contour trenches were also modelled and the effects of the intervention on the watershed were successfully studied.

- It was seen that the upper catchment area remained dry just after the monsoon season, meaning that there was a potential to hold water in that region. Also, this region had thick soil layer which can store the rainwater for some time after the rainy season, which will be slowly supplied to the bottom layer and to the well subsequently.

- The study shows that staggered contour trenches in the upper catchment area of the watershed can prove effective in raising the water levels in the *varchi* well. The GMS – MODFLOW simulations of the contour trenches show that the water levels at the end of the dry season after intervention are around 3 m high than the current scenario.

- The water levels in the well show the sudden decline after January in normal scenario and after mid-March after interventions. This shows that large part of the water stored in the watershed is in the thick soil layer. Once the water in the vadose zone (i.e. in the soil layer) drains out, the storage in the watershed declines suddenly and drastically. This is due to low storage capacity of the underlying basalt layer.

6.7 Implementation

The interventions proposed in the study can be implemented under Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS). Currently, IWMP projects are being implemented in the adjacent areas e.g. Nandgaon IWMP by the Taluka Agriculture Office, Karjat (TAO).

Meetings were organized with the TAO, Karjat to discuss about the implementation of the above interventions in Mograj. The officer showed interest and was ready to implement the interventions under MREGS (Maharashtra Employment Guarantee Scheme) which is now merged with MGNREGS.

Meetings with the local people were held to explain the effect of the interventions (i.e. staggered contour trenches) and their consent was taken (informally). The people having land holdings in the upper catchment of the watershed were identified and consent for the watershed work in the area was taken. As the upper catchment is largely fallow, no serious conflicts about the use of land for watershed works arose.

Meeting with the Gram Sevak, Manohar Agivale were held to discuss about prerequisites for doing work under MREGS i.e. job cards, bank accounts etc.

Meeting with Agriculture Assistant (who was assigned to make plans and estimates) were also organized to discuss about the feasibility and other constraints.

In spite of pushing the concerned authorities multiple times, the work could not be done before rainy season due to delays from TAO, Karjat. The work will be proposed again after the 2013 monsoon ends, i.e. in October 2013.

Chapter 7 Conclusions

The proposed framework of practices required for planning of unit watershed interventions was successfully followed and implemented with above mentioned assumptions and constraints.

The simulation of watershed intervention i.e. contour trenches showed that the well will not dry till the start of next monsoon season and the head at the end of the dry season will be raised by around 3 m.

The storage in the watershed showed increase due to longer retention of water by contour trenches, and showed reduction in runoff.

The drinking water problem of Mograj can be solved partially by implementing the proposed watershed intervention as soon as possible.

As Mograj represents a typical tribal habitation in Western Ghats region, with similar topography, geology and drinking water problems, the practices followed in the present study can be applied to other villages in the region as well.
The Western Ghats region is hilly with undulating slopes. There are numerous 2nd order or 3rd order streams whose catchment areas are very small, thus creating numerous very small sized watersheds (5–50 ha). The open dug wells in the region, which are the prime drinking water sources, lie in these streams. Hence to increase water levels in these wells, work must be done in the catchments of these streams i.e. the small (nano) watersheds or springsheds. At the same time it is important to note that the impacts / benefits of the work done in one watershed will be local and cannot impact a large region. Current IWMP DPRs for the Western Ghats region should reflect this in their planning. Current minimum size of watershed in IWMP is around 5000 ha which is too large for this region. All those streams having wells should be chosen and works should be done in their catchments in order to increase water levels in these wells. This will greatly help in solving the prevailing drinking water issue in the region, which will further help in bringing livelihood stability in the future.

The presence of thick soil layer in the upper catchment / ridge area of the watershed and the fact that this layer remains mostly dry just after the rainy season were the two main results which came out from the analysis. If any of the above facts were not true, the decision of choosing contour trenches as the intervention would be wrong. Or else, if a check dam or cement nala bund in the stream is proposed as the intervention, the effective recharge and would be less than that by contour trenches. This is because, in this case, the soil thickness near the stream is very less, and hence the amount of water retained in that area would have been less comparative to that in case of contour trenches. Hence a check dam would not have been effective in raising the levels of water in the well. This analysis comes from the primary surveys, site visits and simulations i.e. it comes from practice, not alone from theory. Such set of practices need to be evolved for unit watershed interventions.

The broad IWMP guidelines and objectives of rainfed region development, solving drinking water crisis etc. were applied to solving a specific drinking water problem in a small hamlet. The overall success of watershed development lies in solving such specific unit problems by developing similar sets of practices.

Chapter 8 Broader implications and future scope

The present study shows that the performance of watershed development programmes depends vastly on the performance of unit watershed interventions like recharging a well through treatment in upper catchment, terracing of a piece of land on slopes, building water harvesting structure or a bund etc. The success of these unit interventions depend on a set of good practices. These practices include understanding and modeling of needs of the local people followed by planning and design of solution which is the most appropriate in the given situation which is then followed by implementation. Evolution of such practices is an iterative and incremental process with constant interaction with the local people who evaluate and validate the practices. The end product of the whole process is generation of knowledge (Sohoni, 2013).

Currently, the participatory approach in watershed development seems to sideline the evolution of such good practices and instead hands over the critical job of watershed planning to the voluntary sector which is not adequately trained to use and generate technical knowledge. Thus, there is an urgent need for well trained (development) professionals who can interact with the people, understand their needs, pose their problems correctly, gather required data from field through observations and surveys or other secondary sources, do hard-analysis based on the data and needs, design technically correct plans, predict fairly accurate outcomes and implement the plans accordingly.

The absence of such trained professionals may be either due to lack of adequate and required training (i.e. from local colleges) or due to lack of incentive structures for well trained professionals. And this is true for all the development related programmes (like MGNREGS, NRDWP or even programmes like Sarva Shiksha Abhiyan etc.).

- The first part i.e. lack of adequate training can be worked out by including series of courses related to development problems in local engineering colleges which equip students with necessary skills, familiarity of a sector (agriculture, water etc.), to understand and participate in development projects at local level and to think rationally about the developmental problems
- The second issue of lack of incentives is also a critical one. Currently there is no mechanism to tell at which price-point a trained professional should work in watershed development projects. The reason for this is lack of concrete and clear indicators for measuring value created by a watershed project (Sohoni, 2013). Lack of

clear indicators also create lack of proper monitoring and result in poor evaluation methods for measuring performance of watershed projects.

In both the cases though, a standard framework for knowledge and practice generation is required to evolve. The initial steps in this direction should be taken by elite educational institutions like IITs, NITs, IIMs etc. who can become role-models for the local engineering colleges for developing discourse in good practices and for creating trained professionals to work on development projects. This study is the first step in this direction.

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