R8173 - Planning of Sustainable Regeneration in mining areas using tri-sector partnerships

Executive Summary

Project Background

Minerals development, while increasing employment and incomes in mining and related activity, does create serious environmental damage and can undermine other socio-economic development opportunities of local communities. The attempts to redress these impacts have so far been piecemeal and ad hoc with little research or consultation with the groups that are supposed to benefit from these actions. The net result has been a growing disaffection amongst the community. The disaffection and the breakdown of trust in mining regions that is observed is not just linked to company actions, but also to government non-actions. This project attempted to correct this narrow approach through adopting a multi-dimensional approach that integrates a number of activities that range from the technical, to the social, to training and capacity building. The study area falls within the iron ore mining belt of Goa and covers an area of about 11,000 ha. There are 17 villages in the study area and the population is estimated at about 40,000 of which 40% are dependent on mining and 25% on agriculture. The current situation in the area is one were a number of mines are abandoned or closing down, while others are still active. As a result there is an opportunity to start rehabilitation work, which will not only arrest environmental degradation, but also increase the productive capacity of land and the people in the region and enable planning for a time of closure.

Goal

To promote sustainable regeneration in mature, old and closed mining areas based on partnerships between industry, government and civil society.

Purpose

To address issues and constraints to livelihoods arising from mining activity and help communities to create new social development and economic opportunities in mining regions through a tri sector partnership in place. More specifically, the project purpose in each domain is as follows:

Social: a greater say in decision-making, greater capacity for participation, wider knowledge base relating to watershed plans

Economic: identification of new development opportunities

Environmental: An improved technical and social understanding of use of groundwater and improved quality of land for agriculture and other uses and regeneration of derelict land

Project rationale and outputs:

It is increasingly evident that lasting solutions require tri-sector partnerships to address the complex series of social, technological, political and environmental issues prevalent in mining regions. Watershed thinking is emerging as a powerful way of addressing issues that cross disciplinary boundaries, and enable the establishment of systems of social coordination and cooperation to achieve sustainable regeneration. The team felt that combining a multi stakeholder with a watershed approach in the project would help in achieving the project purpose. The process of participatory micro-watershed planning involved a number of activities covering both technical and social aspects as detailed below:

- Economic and legal analysis : Definition of worked out mines and land ownership in the lease area
- Study of hydrological and hydro-geological component including delineating watersheds
- Study of land forms and soil to determine land use options for restoration of degraded land for productive use
- Pilot scale trials of plantation on representative mine degraded land
- International best practices followed in mine land rehabilitation
- Initiate and develop tri-sector partnership
- Social Mapping, micro watershed plans and Social Investment plan
- Conduct intensive training programs for the stakeholders
- Dissemination of various outputs

The project team included professionals with multi-disciplinary skills. **Figures-1 & 2** provide the inter relations between work packages and their interconnections.

Our partnership building efforts involved several meetings with various sub-groups identified within the industry, community and the government. These meetings were held separately and jointly as needed, where we took information back and forth to inform participants about the issues, concerns, constraints and needs of each of the sub-groups. We strove, at all times, to maintain transparency in our work so that trust could be built in the process. Playing this role required greater time and resources than was available under the project. Our work continues in this direction.

Results / Outputs:

1) Backfilling the abundant mine pits with mine rejects without evaluating alternative options that the pit could be used for (eg. Water storage) would amount to a short-sighted approach. Therefore an indicator based decision making tool has been developed to aid the decision making process of mine pit rehabilitation. The tool is a generic one and can be applied universally. Indicators identified and chosen are based on a combination of field experiences and wide ranging discussions with experts in the allied fields. A two fold decision spectrum with water storage in the mine pit on the one hand and back filling of the pit with rejects on the other was adopted while choosing the indicators.
2) A detailed report on groundwater balance in the micro watersheds of the study area has been prepared. Several meetings were held with various stakeholders to

disseminate and discuss the results of the hydrology study. In the comprehensive ground water balance report, the problematic watersheds have been identified as red and black categories (i.e, over exploitation of ground water resources), which include Sirigao, Mulgao and Piligao villages. Immediate attention has to be paid to these areas for solving the water related problems.

3) The pilot scale trials have been successful in establishing different types of soil and water conservation measures in waste dumps. The pilot scale trials of plantation were undertaken in waste dump of about 5 ha area allotted by a mining company. The area was divided into 3 different blocks (models) based on the type of soil conservation measures and topographical conditions. The technique of inward bench terracing (most useful in reducing the slopes of dumps) has shown most worth and efficient means of soil conservation measure in arresting the down flow of silt as well as maintaining the soil moisture for substantial growth of planted species and enrichment of essential nutrients. Besides, inward bench terracing, the adoption of counter bunding technique and rainwater harvesting structures have also shown good results. The technique of placing gunny bag crates (staggered manner) in the high slope areas (slope of 40% to 50%) has shown very good results and the system has proved to be most successful in stabilizing the down flow of dump material. These structures have also helped in the growth of grass and tree species by supplying soil moisture and preventing erosion.

   Before the treatment, dump material was acidic in nature and lacked the essential nutrients. After treatment with necessary amendments, dump material changed in its quality from acidic to basic. It is also noticed that the contents of phosphate and nitrates have increased and the percent of iron content is reduced. In other words, the dump material showed good enrichment of essential nutrients, which helps for the better growth of experimented species.

4) A review report has been prepared based on the international best practices being followed in mine land rehabilitation and a copy of the report given to Mineral Foundation, Goa for reference by mining companies.

5) A note on partnership building process based on our experience has been prepared. Even though there is no formal structure and MoU between the partners, considerable progress has been made towards forging partnerships in specific areas. One such area was to address the issue of rebuilding agriculture in fields which are silted due to run off from mine reject dumps.

   The Business Partners for Development (BPD) literature on partnerships enumerates different types of partnerships including information sharing, consultation, dialogue, informed consent, sharing of work-plans and responsibilities etc… In the context of our project where relationships between stakeholders have been characterized by mistrust, animosity and conflict, the process becomes as important as the final goals set out to be achieved through a partnership. What we see at the end of this project is a slice of this process, which continues to play out beyond the life of this project.

In our experience, stakeholder groups as we commonly know them (community, industry and government) are really composed of a diverse set of actors. For example, the "industry" is made up of large, medium, small and what we term as "rogue" companies. Each of these have differing access to and ability to mobilize resources and information on good practices in mining, necessary to make decision. Here our role was to provide a knowledge base for different actors within the industry so as to present alternatives to current practices (e.g. better dump management practices) as well as bring to the industry a more nuanced understanding to the problems faced by and the needs of the local community.

The "community" is a broad categorization which we found to be composed of different groups of people having different interests. This stakeholder group needed to be 'unpacked' to get a better understanding of how to engage the various groups more effectively. In our project the farmers' groups that we worked with comprised a composite of people who sometimes had divergent interest. Some farmers were wholly dependent on agriculture for a livelihood and therefore were keener to see solutions to their problems, while there were others who also had trucks carrying ore from the mines. In the short-term, to them, trucking seems to pay more than growing a subsistence crop like paddy which can be cheaply bought in the market. The fact that farmers get compensation from mining companies sometimes acts as a disincentive for those not wholly dependent on agriculture to want to rebuild it. Rehabilitating land to make it productive again would mean that compensation and therefore this additional side income would stop. This prevented some from wanting to find solutions and preferred status quo. We noticed that often the degree of association with the mining industry also determined the amount of power, influence and access to resources different groups of farmers had. In this case, our role was to help create a level playing field by building capacity of the least empowered to enable them to clearly articulate their vision of development and participate in working to achieve it. We also needed to assure those associated with the mining industry that working in a partnership would not threaten their livelihoods, a perception common to those associated with the industry. Achieving this required building trust not only between and within stakeholders, but also with the agency facilitating the partnership (i.e. with TERI). All of this is necessary if partnerships are to be sustainable in the long run. It is not difficult, then, to see that these activities take time.

Within the government, those departments impacted by mining activities, but without any regulatory authority were more willing to participate in finding solutions than those who had regulatory authority. Our research shows that government departments having regulatory authority are more susceptible to political pressure and have opportunities for corruption open to them and therefore are less likely to want to change status quo. Additionally, government departments often work in isolation from one another resulting in uncoordinated activities which fall short of addressing the problems. In our interactions with the government departments, we created forums where representatives could discuss issues with each other openly and freely. We also provided results from the technical components of our study to broaden their knowledge base.

6) Based on technical inputs and social inputs from the PRA (Participatory rural appraisal) exercises, conceptual micro watershed plans for selected villages were developed and discussed with various stakeholders on different occasions. These concept plans have been prepared based on: a) identification and evaluation of existing land and water resources in the villages; b) available topographical map and village map; c) discussion with community, local governing bodies and mining companies.

7) More than 500 persons from the study area have been trained during the course of the project through a number of training programmes. The training covered agriculture related subjects; Self Help Groups (SHGs) formation and development; income generating activities like crafts and household items preparation and institutional strengthening programmes. MYRADA (an NGO) who are actively involved with SHGs in building and strengthening peoples institutions and make them sustainable was involved in conducting training programmes. In addition, many individual trainers were involved for various other topics. TERI team members and selected community members visited MYRADA Germalam training centre in Tamilnadu for a short and intensive training on all aspects of SHGs development.

8) A booklet on methodology for evaluation of mine pit rehabilitation using multiple parameter approach has been printed and widely circulated to all the stakeholders. The technical report on hydrology has been distributed to Mineral Foundation, Goa, concerned Government departments and mining companies. A booklet on "Pilot-scale trials of plantation and soil and water conservation measures on representative mine dumps – a case study from North Goa" has been printed and widely circulated to all stakeholders. Three newsletters in local languages have been printed and widely circulated to the stakeholders. A web page has been started and being maintained. A number of dissemination workshops and meetings have been held. A note on "developing alternate livelihoods; the evolution of sustainable solutions" has been prepared.

Conclusions:

1) Tri-sector partnerships:

Partnerships are meaningful and will be sustainable if all partners can clearly articulate, to one another, their needs and constraints and share the responsibilities of achieving common goals. Creating a level playing field between stakeholders therefore becomes crucial and it is this very leveling that some groups try to support or undermine according to where they stand on the power-influence continuum. In our case, it meant working extensively with certain groups within the local community to help them challenge existing power structures within their communities as well as those that govern their relationships with other stakeholder groups outside of their community. Some of this involves a social change in a broad sense that is slow to happen.

While it would be premature to discard partnerships as a means to achieve sustainable regeneration of mining areas, we need to acknowledge that building partnerships is a process. In the context of mining areas where the activity has been going on for over 40-50 years now, this process is bound to take time, where people have hardened positions about how they perceive each other. In the case of developing countries where governments have been seen to be weak with respect to law enforcement in the face of powerful lobby groups and are open to political pressure as well as opportunities for corruption, involving local community through partnerships can be looked at as a step towards improving governance.

While the project was ambitious in its goals, to conclude that partnerships have not worked in this case would be premature. What we see at the end of this project is a conscious and steady progress in this partnership building process by the stakeholders, which we believe would continue beyond the life of this project. Creating partnerships that are sustainable requires continuous engagement and participation of all key stakeholders, something that cannot be fully seen through to its end in a 2-3 year project.

2) Ground Water Resources:

In some of the watersheds the mine pit dewatering has caused depletion in the ground water levels in the adjoining villages causing water stress conditions. The ground water balance report has identified Sirigao, Mulgao, Piligao villages as water stressed due to over-exploitation of ground water resource, which require immediate attention. There is a need to rejuvenate these depleted ground water resources through effective water management practices. The hydrology study results would be useful to the mining companies and concerned government departments for application of the results in the planning process. Using the indicator based decision making tool for mine pit rehabilitation, the suitable and easily available abandoned mine pits should be identified in consultation with mining companies for storage of rain water to recharge the depleted aquifers.

3) Waste dump management:

The pilot scale trials have been successful in establishing different types of soil and water conservation measures in waste dumps. The technique of placing gunny bag crates (in a staggered manner) along the slopes has shown very good results and almost all these bags remained undisturbed during the monsoon season and were most successful in stabilizing the down flow of the dump material. The company management where this pilot study was conducted was satisfied with the results and this practice could be replicated in similar waste dumps with high slopes. A set of recommendations on waste dump management have been given in the report (booklet), which has been widely distributed.

4) Capacity Building Programmes

One of the important insights which has emerged from this project is that local level institutions have a significant and crucial role to play in building and maintaining partnerships. A long term plan for conducting continuous capacity building programmes are essential for different target groups to maintain the momentum gained towards building and maintaining partnerships. In this connection, it is suggested that a multi-purpose community centre for the benefit of community in the mining areas should be set up by the Mineral Foundation, Goa in cooperation with other stakeholders.

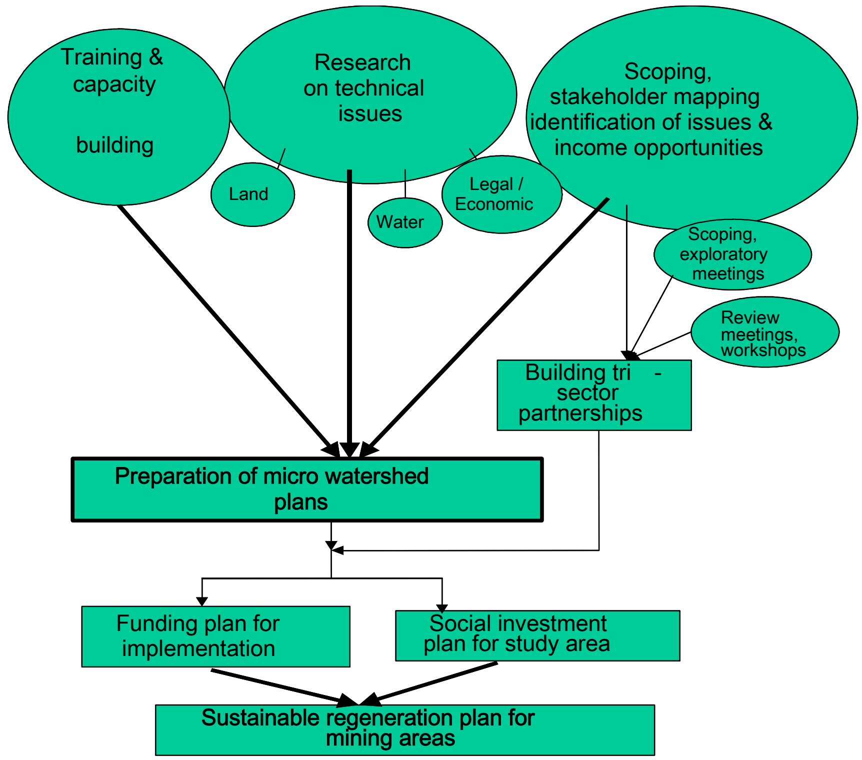

Figure 1. Work packages & Interconnections

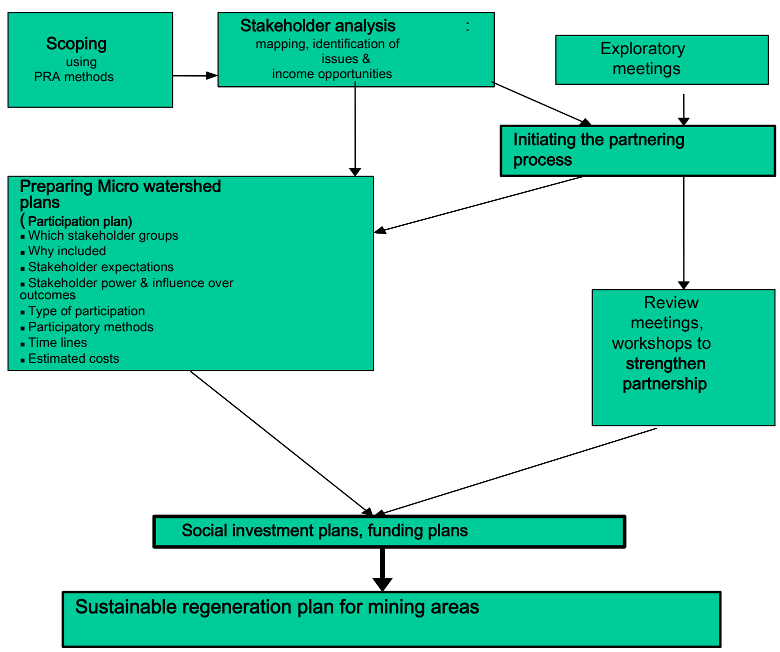

Figure 2. Linking scoping exercise, stakeholder analysis and feeding into the formation of tri-sector partnerships, production of regeneration plan

OUTPUT TO PURPOSE SUMMARY REPORT					
Title: *Planning of Sustainable regeneration in mining areas using tri-sector partnerships* **Country:** *India* **MISCODE:** [*to be inserted by DFID]*					
Report No. R 8173 *[by contractor]*		**Date: 23.02.06**	**Project start date: 1.10.2002** **Project end date:** *30.09.2005*	**Stage of project:** *Final Report*	
Project Framework					
Goal statement: To promote sustainable regeneration in mature, old and closed mining areas based on partnerships between industry, government and civil society					
Purpose statement: To help communities to create new social and economic development opportunities in mature mining and mined out areas					
Outputs:	**Measurable indicators**	**Progress:**		**Recommendation/actions:**	**Rating:**
1. Technical outputs: Identification and description of technical and environmental issues and possible mitigative solutions a) Water • Hydrology study	By Month 18 - Groundwater flow net map - Drainage density variation map - Water table fluctuation maps - Classification of sub-water heads into various categories of water stress classes - Vulnerability maps for al the sub water sheds	*iii) The correlation studies between drainage density and groundwater recharge in the ten sub-water sheds in the study area has been completed.* *iv) The studies of groundwater flownet analysis in the 10 sub-watersheds in the study area has been completed.* *v) Groundwater balance sheet for all the sub-watersheds and their status of groundwater use has been worked out based on:* *b) Estimation of basin-wise water requirement based on sectoral demands* *c) Estimation of basin-wise groundwater recharge based on BALSEQ model results* *d) Estimation of basin-wise groundwater draft.* A detailed report on groundwater balance in the micro watersheds of the study area (North Goa mining belt) has been prepared and is attached vide Annexure - I. A technical paper titled "Present status of ground water recharges and availability in the mining watersheds of north Goa" has been prepared and distributed to Mineral Foundation Goa (MFG), government departments and mining companies. A copy			*[to be completed by DFID*

		of the paper is enclosed in Annexure 2		
• Alternate use of mine pits	Number of mine pits that can be back-filled were identified.	A structured approach based on indicators has been developed as a technical tool to aid the decision-making process of mine pit rehabilitation. The tool is a generic one and can be applied universally. The indicators identified and chosen are based on a combination of field experience and wide-ranging discussions with experts in the allied fields.	The MPR-INDEX Indicator based decision-making tool is a generic one and can be applied universally. It has been distributed to all mining companies and government departments in Goa for testing. The hydrology study results would be useful to mining companies and concerned government departments for application of the results in planning.	
- A standardised system for evaluation of mine pit rehabilitation using multiple parameter approach	Number pits that can be used as water storage have been identified.	A booklet on "A methodology for evaluation of mine pit rehabilitation using multiple parameter approach" has been printed and widely circulated to all stakeholders. A copy is enclosed vide Annexure 3		
b) Land: • Alternative uses of damaged land	• Plan for eco-restoration of derelict land areas	A detailed study has been carried out on rehabilitation of degraded land for productive use keeping in view the deficiencies observed in the existing system. A set of good practices have been suggested based on the results of the pilot scale trials. These are given below: A summary of good practices is given below: **1.** A treatment map should be prepared after survey of mine dump area to be rehabilitated. Types of soil and water conservation measures, number of pits for plantation and space for grass legumes must be depicted on the map.		

		2. The physico-chemical properties of the soil dumps must be analyzed. The quantity of the amendments should be calculated on the basis of the physico-chemical properties of the soil samples of the degraded /dump area. **3.** Inward bench terracing is recommended for slopes less than 35 degree, Gunny bag crates is recommended for areas having slopes more than 35 degree. Gully plugging is also needed where big cracks are seen along the slopes. **4.** Stone pitching is recommended in those mine dump areas where water sources are affected due to heavy erosion. It is the most expensive soil and water conservation method, which may not be recommended to be adopted on large scale. **5.** Toe wall should be constructed around the dump area to check erosion downwards. **6.** Earth working and mixing of the amendments is advised to be completed by the end of March in every Year. The area then should be left for weathering. **7.** 45cmx45cmx45cm pits at an interval of 3mx3m for tree species is recommended working of soil till 10 cm deep is recommended for grass/legume species. **8.** Gypsum and organic manure is recommended to improve the physico -chemical condition of the soil. The use of mycorhizae will also help the vegetation in stress conditions. The quantity will be decided on the basis of physico chemical properties of the soil of the mine dumps. **9.** The planting of tree as well as grass /legume species is advised to be completed before onset of monsoon i.e. by the end of May. **10.** Cashew, Acacia auricauliformis, Acacia mangium, Cocum and Aonla tree species are recommended for plantation in waste dump areas. **11.** Planting of Agave is also recommended behind the gunny bag crates. **12.** Peninisetum pedicellatum, Dedonea viscose and stylosanthes guinanensis are recommended for the coverage of ground flora. **13.** Mulching and artificial irrigation is recommended from November –April. The grasses /legumes are cut on regular		

		basis and converted into organic manure and are advised to be used in the rehabilitation area for three years. **14.** The broken soil and water conservation structures are to be repaired before the onset of every monsoon every year. **15.** After care should be taken for a minimum period of three years. Subsequently the company can decide on the system of management and benefit sharing with the community.		
• Legal: Land and pit ownership issues	• Legal position relating to after mine options for land clarified	This actively could not be completed since proper land records are not available for mining lease areas. MFG is attempting to compile the data from different sources.		
• Pilot scale trails results of plantation		The pilot scale trails of plantation were undertaken in waste dump of about 5 hectare area allotted by a mining company. The area was divided into 3 different blocks (models) based on type of soil and conservation measures and topographical conditions. A summary of results achieved is given below: i) Observed changes in the dump material after treatment Changes have been observed in the quality of dump material after treatment by using the amendments. Before the treatment, dump material was acidic in nature and lacked the essential nutrients. After treatment with necessary amendments, dump material changed in its quality from acidic to basic. It is also noticed that the contents of phosphate and nitrates are increased and the percent of iron content is reduced. In other words, the dump material showed good enrichment of essential nutrients, which helps for the better growth of experimented species. **ii) Status on growth of species** Planted species of tree and grasses have showed substantial growth and it has been observed through monitoring activity from quarter to quarter. Tree species have grown very well in the terraced area and gunny bag crates area in comparison with the	Success of both terracing and gunny bag crate systems of erosion control in dumps has been established and can be replicated by mining companies in other waste dumps.	

		stone pitched area of rehabilitation. Species of grasses in each model, shown a very good media for arresting the down flow of dump material. In overall, species in all the models indicated luxurious growth with respect to time and change in the climatic conditions within the area and there is a less mortality rate (around 10 %). **iii) Status of different types of soil and water conservation** In this rehabilitation process, many techniques have been used for on site soil and water conservation measures as a part of scientific approach in each model. The technique of inward bench terracing (most useful in reducing the slopes of dumps) has shown most worth and efficient means of soil conservation measure in arresting the siltation as well as maintaining the soil moisture for substantial growth of planted species and enrichment of essential nutrients. Besides, inward bench terracing, the adoption of counter bunding technique and rainwater harvesting structures also shown most useful and economical techniques for improved and successful rehabilitation. The 'Gunny bag crates' have been placed with the help of galvanized wire in the high slope area (slope varies between 40 – 50 degrees). This technique of placing gunny bag crates (staggered manner) along the slopes has shown very good results and almost these bags are undisturbed and most successful in stabilizing the down flow of dump material. These structures are also given a very good boost to the grass and tree species to grow in better way by supplying soil moisture and protecting from the erosion. There are other structures adopted along the slopes such as construction of loose boulder checks using the local laterite stones along the gullies and on the upper reaches gully plugging has further helped to control the complete erosion process. **iv) Estimated cost for selective type of rehabilitation** From the experiment, it is noticed that the rehabilitation in stone		

pitched area would cost less than Rs.50,000 per ha (stone pitching itself is a costly affair). Rehabilitation with the help of inward terracing would cost Rs. 1,15,000 per ha but it is found to be very effective method of rehabilitation. Rehabilitation with gunny bag crates would cost Rs.1, 30,000 per ha and it most effective technique in the areas of highly degraded dumps having steep slope.

v) Some general observations:

1. Quarterly monitoring of soil samples were carried out in the rehabilitated site.
2. After care has been taken up for the rehabilitated plot in terms providing timely irrigation facility, weeding, mulching and also followed preparation of basins.
3. At the time of rehabilitation, previously prepared structures of soil and water conservation measures have been repaired before the onset of monsoon, wherever necessary.
4. Replacement of plant species was carried out in some of the places (at very few places replacement has been carried out) and broadcasting of seeds has been also done on some parts of the rehabilitated site to cover up uniform grass.

vi) A booklet on “Pilot-scale trials of plantation and soil and water conservation measures on representative mine dumps – a case study from North Goa” has been printed and widely circulated to all stakeholders. (mining companies, government departments and local community) as a part of awareness programme on dumps rehabilitation.
A copy is enclosed vide Annexure 4. A group of community members and representatives from agricultural department of the government were taken to the experimental site for a study tour. Different methods adopted for erosion control and water and soil conservation measures and their benefits were explained to the group.

• Review of good practice in mined land regeneration: International perspective		A final review report has been prepared based on the international best practices being followed in mine land rehabilitation. No single all-purpose best practice exists or is likely to be developed in the future. Indeed, failure to account for the various external factors that significantly influence the implementation of best practice at project level is likely to lead to important site-specific factors being ignored or misjudged, with subsequent unwanted and unexpected flaws in the regeneration process. Therefore, the emphasis in this review is as much on the process of identifying appropriate best practice as it is about best practice itself. Although concepts may be transferred from site to site, a true solution depends on the abilities of all stakeholders to adapt a conceptual regeneration design to fit the context and requirements of the site. Best practice is therefore best viewed as a distillation of collective expertise and knowledge that should meet the following criteria: - Widely accepted and applied. - Enables legal compliance. - Meets industry and community expectations. - Includes suitable involvement and consultation. - Gives appropriate consideration to indigenous peoples. - Transparent. - Integrated into the whole lifecycle of the mine. - Sustainable, or leading to sustainability. A copy of the report on review of good practice in mined land regeneration prepared by University of Warwick is attached vide Annexure - 5 Copies of the report have been given to Mineral Foundation, Goa for reference and use by the mining companies.		

2. A tri sector partnership arrangement involving the mining companies, office of the district administration, NGOs and community leaders (village/block level panchayats).	By Month 24 • A tri sector partnership arrangement in place; • statement of objectives; • identification of tasks and workplans, skills and resources needed; and • matrix of responsibility	Tri-sector Partnership During the project period, several meetings were held with community members and other stakeholders to enable them to participate in partnership building processes. As reported earlier, it has taken longer than expected to consolidate partnerships due to various challenges the team faced during the process. Time was spent addressing the power asymmetries between different stakeholder groups so as to ensure that the community is able to participate effectively. The stakeholders now seem open to the idea of forging partnerships on different fronts. Even though there is no formal MoU between the partners, considerable progress has been made towards forging partnerships on specific areas. A note on partnership building based on our experience has been prepared and is enclosed vide Annexure 6. A description of the meetings and workshops held in the partnership building process is also included in the Annexure. A farmers' group in Cudnem village, the Falwada Tenants Association (FTA) was keen to rebuild agriculture on their fields that have got silted over the years with run-off from mine reject dumps. In dissemination meetings held we presented to the FTA the different possibilities to restart agriculture on affected fields. Information disseminated included possibilities of silt removal, dump management techniques taken up under this project, different government schemes which support rebuilding of agriculture, concepts of partnerships and sustainable regeneration. These meetings were also attended by representatives of the Department of Agriculture as well as those of the Minerals' Foundation[1]. In the case of Cudnem, the main problem with agricultural fields is that of reduced yields. During the monsoons the silt that is brought down from the mine-reject dumps enters the agricultural fields. This is the main cause of reduced yields since the silt is low in nutrients and decreases the productivity and fertility of the soil.	The MFG has to play a major role in maintaining the current momentum in forging partnerships and in identification of various tasks and convert them into action plans. This role fits in with their charter.	

[1] The Minerals Foundation is a foundation supported by the mining companies and is geared towards addressing environmental and socio-economic impacts to the local community, from mining.

		A common solution to this problem being followed by the companies has been to offer farmers a monetary compensation towards the damages and loss suffered by them. Sometimes compensation also accounts for the cost of removing silt to continue farming. Farmers who are unaware of their rights to compensation or who are unaware of how to access compensation are left out. The amount of compensation paid for crop loss is low and does not include the cost of long term damage to the land or the opportunity cost. Even though farmers are compensated for damage to their fields, often the amount paid does not fully account for damage suffered by them. While it is possible to continue agriculture, it becomes increasingly costly to the farmer. With increases in local cost of labour, farmers often say they run into losses. Consequently, farms are left fallow and the compensation money acts as an incentive not to farm. This culture that has been built over time, is not sustainable, although it may seem like a sound choice in the short run. In the long run, silted fields left untended can suffer permanent damage. People become dependent on a temporary, irregular and inadequate income that is compensation. When mines close down, the compensation that they receive will stop and they will be left with unproductive and infertile land. Over several meetings it became evident to the farmers that if they want to restart agriculture, then a holistic approach would be needed. Discussions between farmers, government officials, and the Minerals Foundation, helped identify areas where solutions need to be found. These include desilting of fields, preventions of further run-off from reject dumps, rejuvenating the fertility of the soil and making water available for agricultural activities. There was general agreement that agriculture can be effectively restarted in this village, and that there is a role for each of the partners in meeting this common goal. In principle, the stakeholders have agreed to participate and make resources available as will be required to regenerate agriculture. Thus addressing specific issues - regenerating agriculture - with	The practice of compensation can only serve the limited purpose of meeting the short term needs of the affected and vocal farmers. It cannot be sustainable in the long run especially when the mines will close down. A holistic plan of desilting agriculture fields, ponds etc., wherever feasible has to be prepared and implemented in phases.	

		existing groups has been more effective in addressing the issue of sustainable regeneration. Since the problem was well defined, the community already organized into a tenants' association, there existed recognized leadership within the group, a menu of possible solutions made available to trigger the imagination of the local community helped catalyze the process eliciting a positive response from the tenant's group, the government and the Minerals Foundation. One other attempt in forging a partnership arrangement has been the concept of developing multi-purpose community centre (MCC) for the benefit of the communities in the mining area. The idea was floated in the dissemination workshop with the stakeholders held in March 2004. The Mineral Foundation has obtained an in-principle clearance from their Board for developing the concept into a plan. In this connection, the Mineral Foundation has organised two workshops/meetings in April 2005 with NGOs working in Goa including Teri to discuss on the MCC including its objectives, functions and the way to move forward. The main purpose would be to strengthen the local level institutions and SHGs and assist them in promoting income generating activities by the community The lessons learnt from the partnership building process are briefly described below. 1. One of the most important insights which have emerged from this project was that local level institutions have a significant and crucial role to play in building and maintaining partnerships. They help build a common vision in the community. In areas riddled with conflict and tensions, they help build trust. They make mobilizing resources easier. They give legitimacy to the nebulous identity often referred to as "the community". 2. Participation is more likely from community members if they are organized in "*affinity groups*" i.e. such people that have similarities or share some common reality and are therefore more likely to want to work with one another. These may be people of the same caste, religion, socio-economic group etc.	The MCC is an acceptable concept to all the stakeholders and has to be planed and properly executed by the MFG.	

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It is more difficult to organize people around broad goals like “sustainable regeneration” or “village development”. Precise and clearly defined goals like “restarting agriculture on a fallow plot” or “building access roads to a particular village”, something which is more concrete makes measuring success more tangible, which encourages all stakeholders and builds trust between and within groups. Clearly defined goals also reduce the influence of politics in partnership building.
Partnerships cannot be divorced from local politics yet it is important not to get caught in it. To be conscious of and recognize the influence local politics may have on partnership outcomes and work with the local politics is part of the challenge of building partnerships

Some of the constraints faced by the different partners in building partnerships are listed below:
Community:

Lack of leadership
Lack of ability to develop and articulate a common vision
Diverse interests within community
Suspicion and mistrust within different components of community
Absence of strong local level institutions

Industry:

Unable to find accountable and reliable community-based groups to work with
Limited understanding of the local community and its needs
Stereotypical ideas about community attitudes and what it wants

Government:

Difficult to find champions of the cause in government
Constrained by lack of staff to carry out monitoring and enforcement

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		• Unavailability of appropriate data and testing laboratories to undertake necessary analysis regarding impacts of mining		

3. Social Mapping, micro watershed plans and social investment programmes: Identification and development of various social investment themes that lend themselves to implementation through tri-sector partnership	By Month 21 • Micro watershed plans for the study area based on information and studies of the technical package • SIP worked out for the study area that draws on the micro plans	Mining has created a fair degree of wealth within the local community, the benefits of which can be seen in homes that are fitted out with all the trappings of modern, upwardly mobile social groups including TVs, stereos, scooters etc. Yet, this veneer of wealth wears thin in the face of closing mines. In an area where traditional assets such as land and water have been degraded by mining the community has very little insurance against the fluctuations in the industry. While mining has created opportunities for men in the community, women's options have in fact shrunk. As agriculture has been negatively affected women working in the fields have lost a productive opportunity. Simultaneously, there are no opportunities for women in the mining sector. Research on the socio-economic conditions of the study provided several interesting insights that fed into the planning of capacity building programmes. The main activities of women in the mining areas are household tasks and child rearing, agricultural work on their own fields (where agriculture is still being practiced) and agricultural/horticultural labour work in paddy fields and cashew plantations. Very few women work in other productive sectors. While interacting with women during participatory research exercises several women expressed an interest in taking up non-farm based income generating activities such as production of household and craft items. With this in mind, we attempted to design a variety of training programmes for the community with a focus on women. The process of building alternative livelihoods is clearly crucial in bringing back some resilience into the community. Yet, in order to bring about this shift, the community members have to fully understand and believe in the need for bringing back diversity of livelihoods at an individual level. In turn this requires people to have a vision for themselves, for their families and for their communities. In addition to providing technical training to support alternative		

		livelihoods, NGOs need to play a role in creating structures and forums through which community members can begin to reconstruct their own lives, identify their own needs and then plan accordingly for new livelihood opportunities. A note on developing alternate livelihoods: the evolution of sustainable solutions is enclosed vide Annexure 7. The following micro plans have been discussed in detail with the stakeholders on many occasions during the course of the study. These can be converted into possible implementable schemes (SIP's) 1. Rebuilding agriculture – Falwada Tenants Association 2. Strengthening SHGs – capacity building programme & Federation of SHGs 3. Jatropha plantation – demonstration 4. MCC for the benefit of SHGs 5. Other schemes (concept notes) on rebuilding agriculture		
		(i) Rebuilding Agriculture: Based on many meetings with the community, one of the Farmers Association in Cudnem village (Falwada ward) showed interest in developing a plan for restarting agriculture in their silted fields. Discussions have been held with concerned stakeholders (Mineral Foundation and government officials and the Farmers Association) and they have agreed for a *Micro-plan* to be prepared. The total silted agriculture land in Falwada is about 19 hectares and agriculture has stopped totally and about 35 families are affected. A micro plan for restarting agriculture in the silted fields has been prepared. The mining companies have initiated action for preventing further flow down of material from the waste dumps.	A tentative plan for rebuilding agriculture in Falwada was prepared and presented by the Falwada Tenants Association in the final dissemination workshop held in May 2005.	
		(ii) Capacity building programme for Strengthening of SHGS and local level institutions.	The MFG, which is a voluntary association of mining companies, is involved in investing in	

		We feel that strengthening local level institutions would be a more useful intervention and we anticipate that the development of economic activities or alternative livelihoods will flow more easily and naturally once SHGs (or other local level groups) are up and running successfully. We also realised that the community needs to be able to have their own vision and set their own targets and goals rather than have us plan for them. In order to develop these capabilities each SHG needs to be a well functioning unit, which in turn requires: o Clear rules and regulations applicable to all o Democratic functioning of groups and rotation of leaders o Strong relationships with NGOs, government departments and other institutions o Ability to resolve conflicts with the group o Proper maintenance of records, of group meetings, activities, and finances With these points in mind, we began the process of institutional strengthening through a variety of activities and training modules on book keeping, vision building, conducting SHG meetings etc. Importantly, we also accompanied a group of 12 women to the MYRADA training centre in Tamil Nadu where they were exposed to very successful SHGs along side three days of intensive workshops. To provide intensive institutional building programmes to several groups in the mining area will require a core group of well-trained community resource persons. Investing in community leaders or resource persons ensures that the skills and capacities required stay within the community. Additionally, the promoting NGO can hand over the role of training to the community and continue to play a role in oversight and monitoring. In order to reach this stage, the NGOs working in the area could come together to identify potential community leaders and to support an intensive training programme for trainers. A group of community resource persons (who are potential	social development and environmental protection activities in the area. They have taken up a number of programmes on women empowerment in the area with an aim to strengthen the women groups with skills in alternate income generating activities. The foundation in association with Goa Business Trading Board has trained the women in tailoring, computer education, fashion designing, embroidery, agarbatti and candle making, soft toys manufacturing, rexin bag manufacturing, cooking and catering, decorative wax art. The foundation also organises village health camps, medical assistance to elderly people and also provides funds for infrastructure activities for empowering the education institutions. The foundation has carried out number of activities related to	

		leaders within the SHGs) are being trained on group strengthening. Myrada (an NGO) with whom we have been interacting closely are involved in this process. They have developed a format of 10 modules and the whole programme would be spread over 12 months. The programme has commenced and will go on till October 2006. Each module consists of three days of intensive training followed by implementation of what has been learnt during the month. SHG Federations: The formation of a Federation of SHGs has been discussed with the MFG. The need of promoting a federation of SHGs is i) to Strengthen the SHGs through providing a forum for regular interaction and networking, ii) For information dissemination to SHGs and iii) for undertaking such activities that benefit the SHGs and communities but cannot be taken up by individual SHGs on their own. "A Concept Paper on Federations of Self Help Groups" prepared by MYRADA is enclosed vide Annexure -8. The federation model put forward by MYRADA clearly presents the goals, structure, functions, eligibility criteria for a federation. Importantly, it provides some tips on the NGOs role as a promoter of SHGs and federations and guidelines for the NGOs withdrawal from federations' activities. (iii) Jatropha Plantations : As reported in the previous progress report a dissemination workshop with mining companies and government officials was organised to promote plantation of Jatropha in the reclaimed land (waste dumps and backfilled areas). Subsequently two companies have offered to allocate about 15 hectares of waste dump areas for a demonstration project. Discussions were held with these companies and proposals/schemes would be prepared for	water harvesting and managing the important natural resources through i) participatory watershed development program ii) Desilting and renovation of existing lakes and ponds and iii) desilting of a number of nallahs in the area. TERI is working with MYRADA to develop the training modules in local language.	

		Jatropha plantation as a demonstration project beyond the project duration. The success of the plantation would result in more degraded/reclaimed areas being offered by the companies for bio-fuel plantation. *Jatropha* is a fast growing plant and can achieve a height of three meters within three years under a variety of growing conditions. A perceived advantage of *Jatropha* is its capability to grow on marginal land and its ability to reclaim problematic lands and restore eroded areas. *Jatropha* products from the fruit – the flesh, seed coat and seed cake – are rich in nitrogen, phosphorus and potassium (NPK) and are rich manures that improve soil. *Jatropha* hedges and shelterbelts by improving the microclimate and providing humus to the soil, which can further enhance the productivity of other agricultural crops on applications. The seed of *Jatropha* contains (50% by weight) viscous oil, which can be used for manufacture of candles and soaps, in the cosmetics industry, for cooking and lighting by itself or as a diesel/ paraffin substitute or extender. This latter use has important implications for meeting the demand for rural energy services and also exploring practical substitutes for fossil fuels to counter greenhouse gas accumulation in the atmosphere. Objectives: The main objective is the economical and sustainable management of mined out wastelands through *Jatropha curcas* and mycorrhiza combinations. Enhanced establishment and growth of these species by increasing nutrient uptake and stress tolerance by application of mycorrhiza. Methodology : (a) Wasteland soils would be initially analyzed to ascertain their difficult problems (chemical analysis) for a range of parameters for better understanding of the nature of problems. Environmental based selection of plants *Jatropha curcas* from the vast germplasm would be made. (b) Nursery		

		would be created for mass multiplication of the selected plants for their plantation in the degraded lands later. At the nursery stage inoculation of the plants with mycorrhiza biofertilizer and other beneficial microorganisms would be given to the plants for better tolerance properties to stresses and enhancing their nutrient uptake capacity. (c) Large-scale plantations would be made at the site with a purpose for ensuring economic gain and value addition in a reasonable profitable way in future. (d) Process demonstration of bio-diesel production and its use and application would be made for its use at the industrial level. After the de-oiling of the seeds, the de-oiled cake would be made available for use in the vermicompost unit of the industry for superior quality vermi-compost. (iv) Multi-purpose community centre. Already reported under item –2 (tri-sector partnership) above. (v) Concept plans for many viable schemes especially for rebuilding agriculture in the area was presented to stakeholders in the dissemination workshop held in March 2004. Integrated micro plans (in brief) have been prepared for selected villages based on a) identification and evaluation of existing land and water resources in the villages b) available topographical map and village map and c) discussion with the community, local governing bodies (Panchayats) and mining companies. These are given in Annexure 9.	Once the local level institutions are strengthened some of these concept plans can be converted into micro-plans for implementations.	

4. Training and development of Community tool boxes: Capacity of partners for effective participation in the preparation and implementation of various plans for social development	By Month 24 Training of and Increased capacity of key motivators comprising at least 0.5% of population of 45000 in the study area	More than 500 persons have been trained during the course of the project through a number of training programmes. A complete list of capacity building programmes conducted from May 2003 to March 2005 is enclosed vide Annexure 10. The training covered agriculture related subjects; crafts and household items preparation and institutional strengthening programmes. An alternative livelihoods programme was also organised early in the project, which attracted about 325 participants. Women members from the community	Capacity building of the community and SHG members will be an ongoing activity and ultimately MCC (once it is established) can take up the responsibility of these activities.	

		outnumbered men in all these programmes. Based on a review of the training programmes conducted in 2003, it was decided to take the assistance of MYRADA (an NGO) who are actively involved with SHGs in building and strengthening peoples institutions and make them sustainable. With MYRADAs help both TERI team members and selected community members were taken on a visit to MYRADA Germalam training centre in Tamilnadu for a short and intensive training on all aspects of SHGs development. TERI's team involved in capacity building and institution building attended a five day training programme on strengthening community institutions, including self help groups and watershed committees. The training programme was conducted by MYRADA another NGO working intensively in the field of institution building. Some important lessons learnt at the MYRADA training program The importance of institution building - MYRADA is engaged in building local level institutions that are strong, sustainable and built around the principles of participation, gender sensitivity, equity etc. Through institution building comes empowerment of individuals, the group and then the community as a whole. Following from this, people- as individuals and as groups can begin to affect change, take control over their resources, make their own decisions and solve their own problems. As the groups get stronger, the NGO or facilitator has a smaller role to play since the groups will chart their own course, make their own choices, decisions etc. This is the true meaning of independence- people having control over their own lives, this concept also gels well with Sen's capabilities approach where development is seen as giving communities and individuals the skills and capabilities to chart their own course rather than material commodities. One of the backbones of building strong local level institutions is the idea of group savings, an approach adopted by TERI as well. An important aspect of savings is accounting for the money saved. Proper bookkeeping not only helps keep track of the money but also teaches numerous skills to these thrift groups including numeracy, accounting, writing of minutes, conducting and participating in	An important lesson learnt is that community development and social change takes a long time, sometimes the change comes only after one generation. Realising that projects are usually short term there is a need to recognize this constraint faced by those involved in action research, and set goals which can be realistically targeted within the given timeframes.	

		meetings etc. These help develop ideas of transparency, accountability, participation, equity etc., within the community and are the pillars of strong local level institutions. Another factor which helps build local level institutions is assisting communities develop a strong vision. The vision must be 'theirs' and not something "we" see as good for the community. Our role in this process needs to be that of a facilitator so that we elicit answers and solutions from people and not preach to the community about solutions to various issues they face. By eliciting responses group members develop an ownership over ideas and concepts and thus are more likely to bring them into practice.		

5. Dissemination	Over project period • A quarterly pamphlet (Months, 5, 9, 13, 17) in the local language providing updates on meetings and issues raised • WebPages started and maintained • 3. Minutes of meetings and workshops	A number of group meetings were held with different stakeholders on many occasions during the project duration. Three dissemination workshops were held (March 2003, March 2004 and May 2005) where all the three stakeholders were represented. Three newsletters in local language were printed and circulated widely in the communities on topics like "Introducing partnerships" and "The role of local level institutions in partnership". Booklets on pilot scale trials of plantation and A methodology for evaluation of mine pit rehabilitation were printed and widely disseminated. Some research papers have been published in refereed journals. A list is given in Annexure-11.		

6. Well defined funding Plan for Phase-2 (implementation)	By Month 24 A Funding plan	A list of available funding options for different schemes under various government departments have been compiled (for detail see annexure – 12). To take up identified resource development activity in the village, it is very important that form a village level institution called "Resource development Centre" or "Watershed Association" which should be registered under the Societies Act 1860. By registering under the society Act, the village level institute will	

		become a nodal and legal set up for entire community. This village level institute should include identified members of land owning families as well as land less families (this may include the members of Tenant associations/ shetkar committees/ members of scheduled caste / members of BPL / communidars etc). This is very important, as most of the government department schemes help the communities if they are in Group/ larger number rather than individual. On the other hand, it also helps community to manage the funds and developmental activities in a systematic way.	
7. Monitoring Stage	By month 36 2 monitoring reports at intervals as agreed		
Purpose:	**OVIs**		
To help communities to create new social and economic development opportunities in mature mining and mined out areas	By end of phase I of project : • Awareness of opportunities and rights by local communities • Identification of rehabilitation options and costs for land and unused pits in the study area • Clear plan of the possibilities for sustainable regeneration of region and communities	The communities are well aware of the opportunities / rights and issues that arise in the mining area. This has been achieved through a number of meetings / workshops, training programmes, visits and dissemination material. The following technical reports have been prepared as outputs from the project. i) Hydro-geological study reports. ii) A methodology for mine pit rehabilitation using multiple parameter approach. iii) Pilot scale trials and soil and water conservation measures on a representative mine dump. iv) Plan for eco-restoration of derelict land areas. v) Review of good practice in mine land regeneration in other countries. All these reports have been disseminated to the concerned stakeholders. A note on “Developing alternate livelihoods: the evolution of sustainable solutions” has been prepared. The following micro plans have been discussed in detail with the stakeholders on many occasions during the course of the study. These are likely to be converted into possible implementable schemes. 5. Rebuilding agriculture – Falwada Tenants Association	

		6. Strengthening SHGs – capacity building programme & Federation of SHGs 7. Jatropha plantation – demonstration project. 8. MCC for the benefit of SHGs 9. Other schemes (concept notes) on rebuilding agriculture in five selected villages.	
	• A tri-sector partner ship in place	• A note on partnership building process, based on our experience in the last two years have been prepared. Even though a formal tri-sector partnership may not be in place, the stakeholders have opened up to the idea of forging partnership on different fronts. Rebuilding agriculture is one of the themes which the partners are keen to address and workout the role of each partner in meeting the common goal. The other theme being considered is on developing a multipurpose community centre for the benefit of the communities.	
	• Plan of funding options and sources	• A list of available funding options for different schemes under various government departments have been compiled and disseminated in meetings with the stakeholders. The micro plans, which are being developed would include the funds requirement and the possible sources of funding.	

Annexure - I

GROUNDWATER BALANCING IN THE TEN MICRO-WATERSHEDS OF NORTH GOA MINING BELT, GOA, INDIA

hydrological assessment for EIA reporting in mining

2003-2004

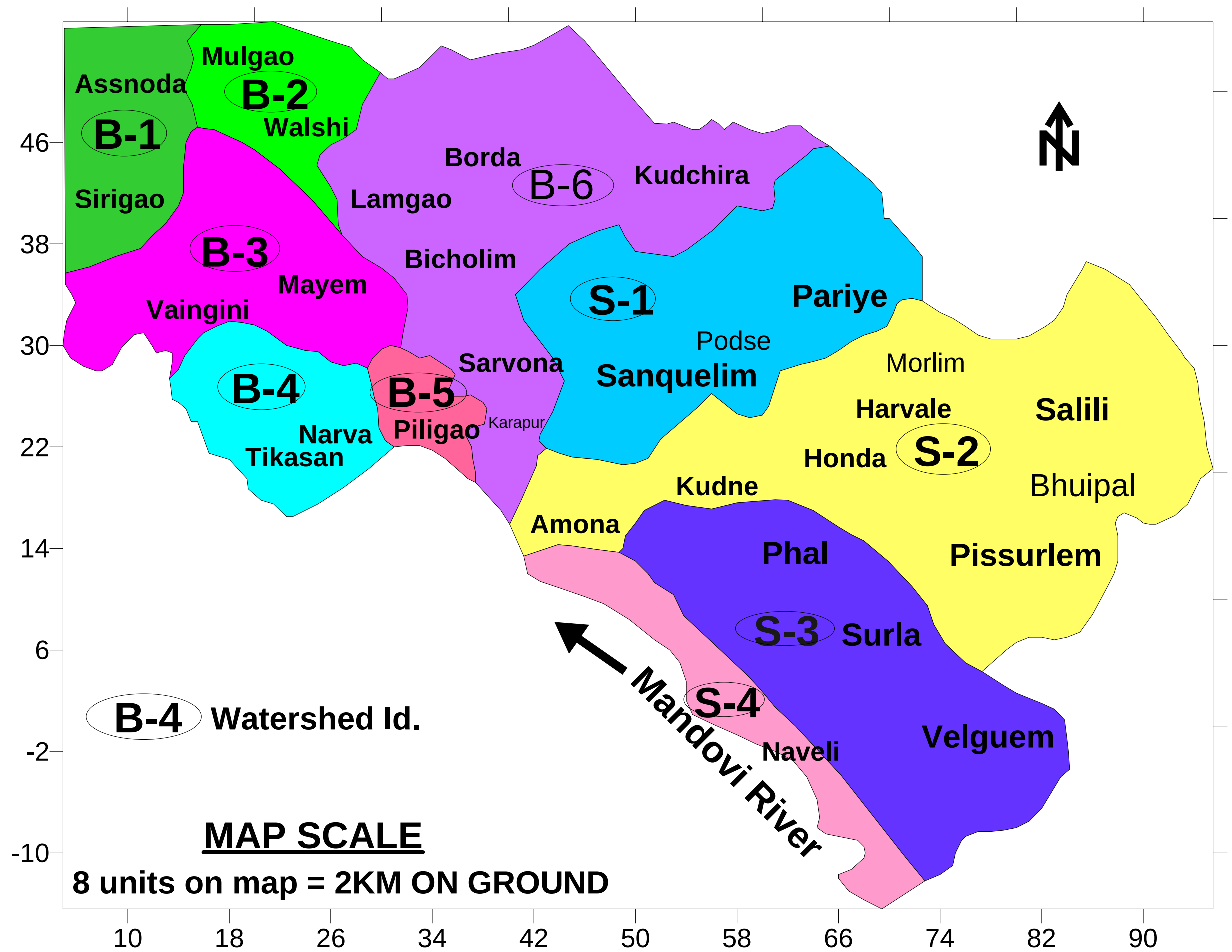

Fig.1: Location map of micro-watersheds in north Goa mining belt,Goa

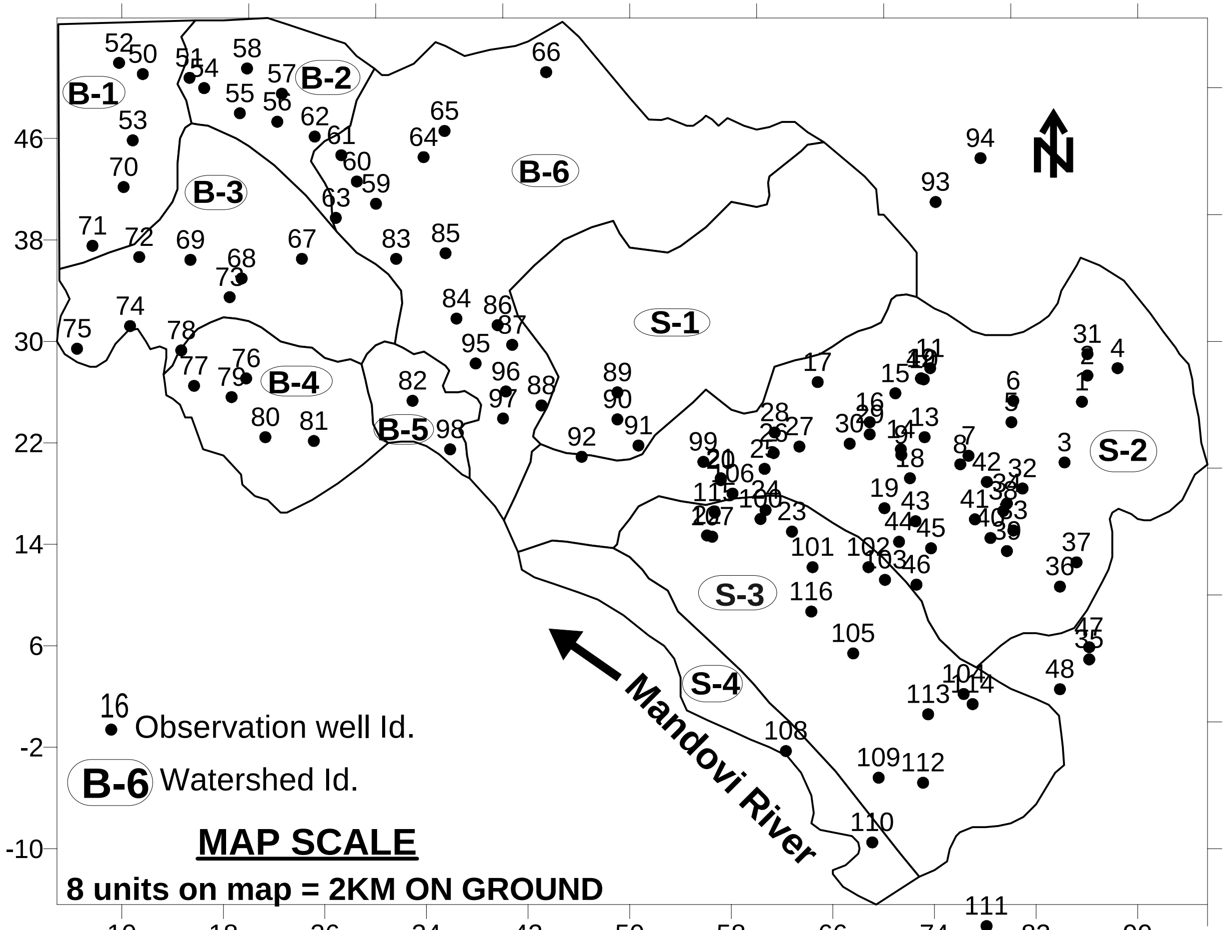

Fig.2: Locations of observation wells in different watersheds of the study area

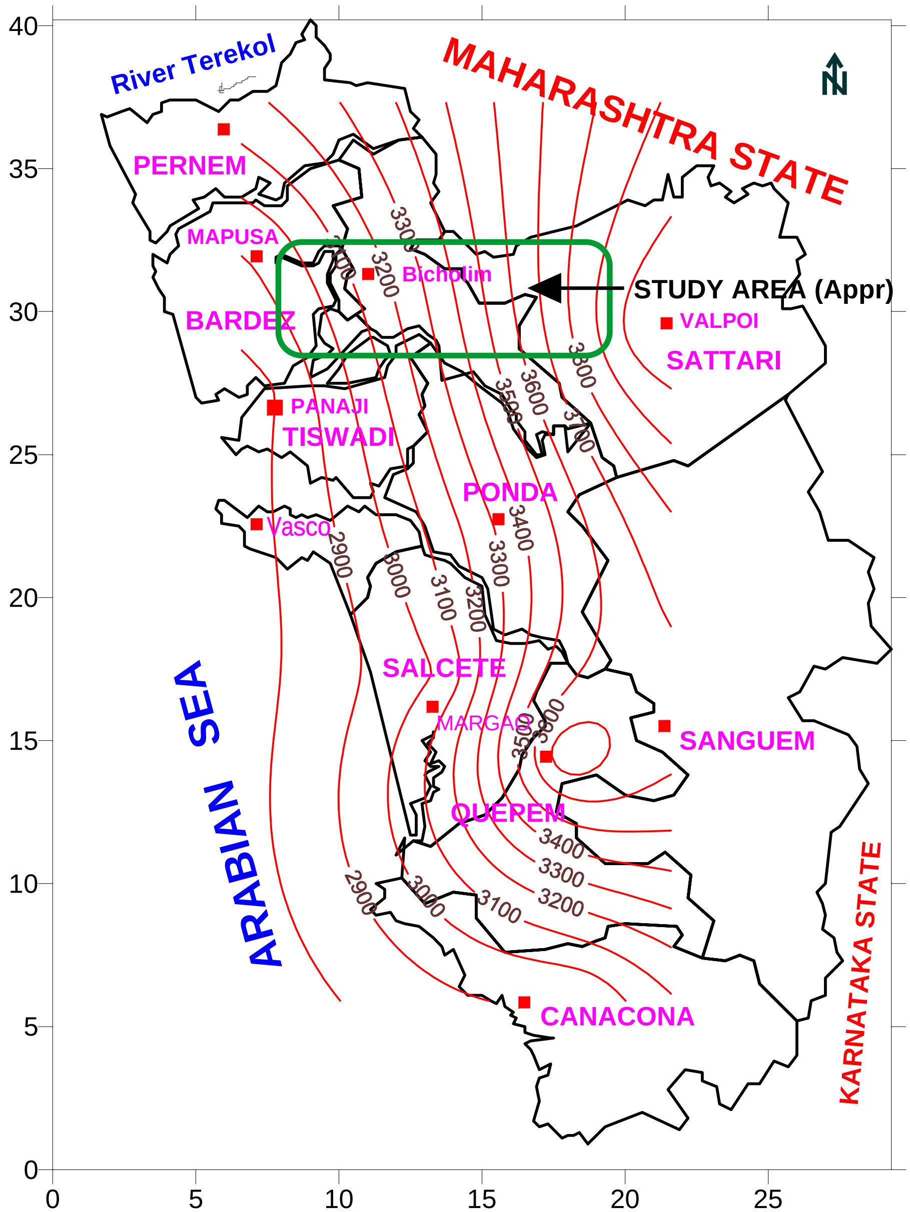

FIG.3: NORMAL MONSOON RAINFALL(MM) DISTRIBUTION OVER GOA

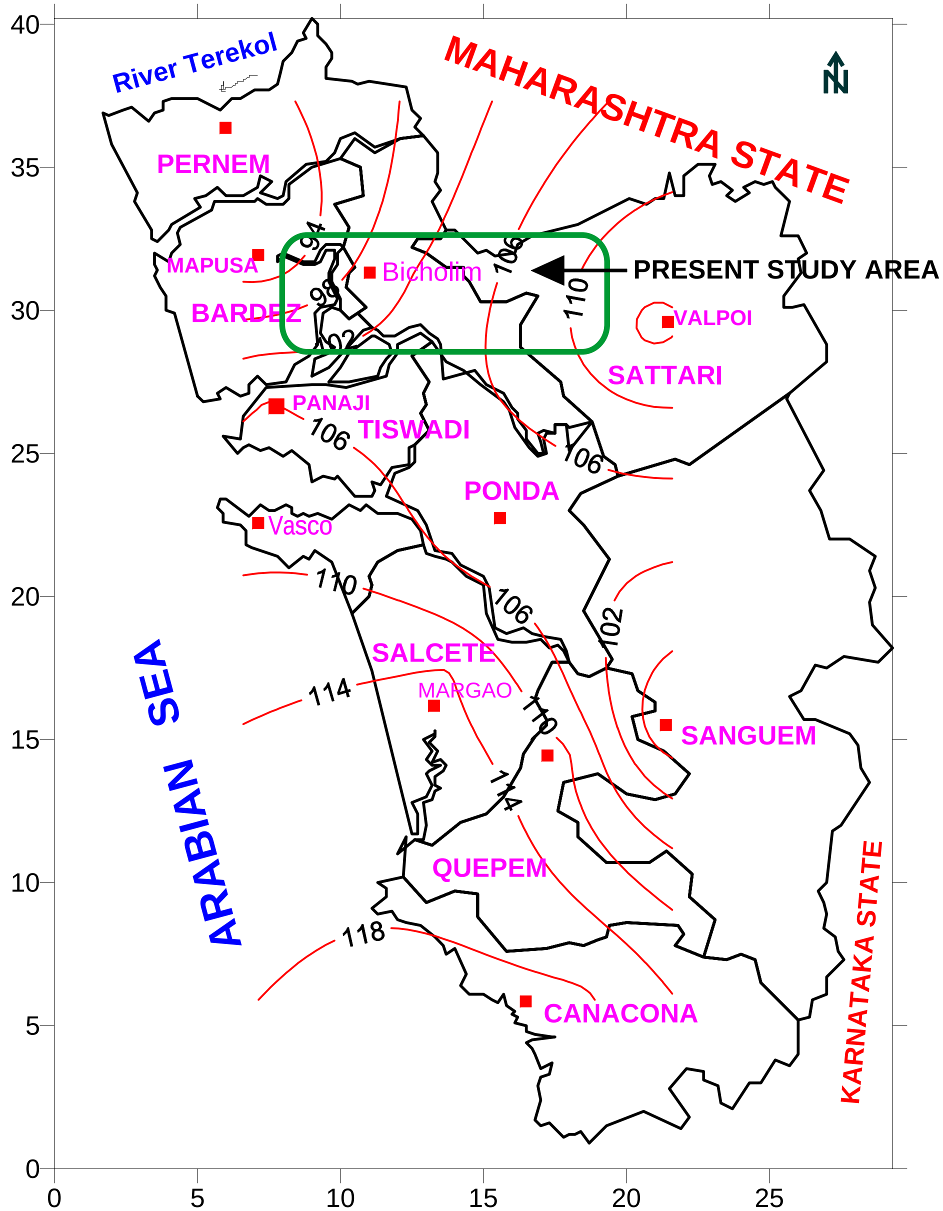

FIG.4: NORMAL NON MONSOON RAINFALL(MM) DISTRIBUTION OVER GOA

Table. 1: Details of Observation Wells Established in the Mining Belts of North Goa

Well No.	Well Owner & Location	Well type, radius (m), & Age	Well Use	Water Quality	Summer Water levels	M.P. ht. above grd (m)	Well depth b. MP (m)	MP ht. above msl m)	Geology Aquifer
01	Panchayat well located on left side of approach road to Bhuipal village about 800 m from main road	Circular, 2.9, 20 Yrs	Domestic	Good	Dries in summer	0.80	10.00	50	Near DMC mine, 1Km away
02	Panchayat well located in Bhuipal village about 600 metres from Well # 01	Circular, 2.0, 17 Yrs	Domestic	Good	Dries in summer	0.90	11.88	58	Near DMC mine, 2Km away
03	Mr. K.Raghunath's, locate about 10m away from nala, in the new settlement area about 800m from the main road to Valpoi and on right side of approach rd. to Salili	Circular, 3.0, 5 Yrs	Domestic	Good	Dries in summer	0.65	6.65	50	Weathered laterite and clay
04	Village well located near nala and about 50m away from hill where rock quarrying is done	Circular, 3.3, 20 Yrs	Domestic	Good	Does not dry in summer	0.94	4.32	65	Only well in the village
05	Panchayat well located on the left side of approach road from Salili to Honda about 10m away from nala	Square, 1.6x1.6, 25 Yrs	Domestic	Good	Does not dry in summer	0.60	4.68	48	
06	Private abandoned well located on the side of nala below the road bridge on right side of Hoda-Keri road	Circular, 3.4, Old	Domestic	Good	Does not dry in summer	0.50	7.22	50	
07	R.Jotbai Pednekar well located on the right side of Keri-Honda approach road about 300 m from main road to Valpoi in Honda	Square, 2.15x2.15, 3 Yrs	Domestic	Good	Dries in summer	0.40	9.40	38	Weathered laterite
08	Well of Mahadev temple just on road side in the corner of main road and approach road from Keri	Square, 2.5x2.5, Old	Domestic	Good	Dries in summer	0.50	5.30	40	
09	Private well located on the left side of Sanquelim-Valpoi road about 50m away in the house compound	Circular, 2.65, Old	Domestic	OK	Dries in summer	0.70	8.68	35	
10	Panchayat well in Harvale village	Circular, 2.57, 15 Yrs	Domestic	Good	Does not dry in summer	0.75	5.62	45	

Continued…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
11	Panchayat well near the temple and close to nala on right side of the road near Primary health centre of Harvale village	Circular, 2.85, 20 Yrs	Domestic	Good	Does not dry in summer	0.70	7.50	40	Laterite. Unconfined.
12	Panchayat well close to nala but in the house compound in Harvale	Circular, 2.0, Old	Domestic	Good	Does not dry in summer	0.82	9.10	52	Laterite. Unconfined.
13	Mr. Halsi Jamel Ahmedi's well in his house property on the right side of the Kuchcha road from Honda to Harvale	Circular, 1.75, 1 Yr	Domestic	Good	Dries in summer	0.60	10.43	55	Laterite. Unconfined.
14	Private well in the agricultural field on the left side of Honda-Sanquelim road about 100m away from road	Square, 3.68x3.68, Old	Irrigation	Good	Dries in summer	0.65	4.85	38	Laterite. Unconfined.
15	Well belonging to Mr. Subhash located in the house compound left of Honda-Harvale approach road	Circular, 3.0, 12 Yrs	Domestic	Bad	Dries in summer	0.70	8.68	40	Laterite. Unconfined.
16	Well in private property on the right side of Honda-Harvale approach raoad and close to high way to Valpoi	Circular, 2.49, New	Domestic	Good	Dries in summer	0.60	7.63	45	Laterite. Unconfined.
17	Govt. well in the outskirts of Sanquelim housing board land on the right side of Honda-Sanquelim road near to open water body	Circular, 3.4, New	Domestic	Good	Dries in summer	0.80	8.24	55	Laterite. Unconfined.
18	Well on the left side of Honda-Dignem road 50m away	Circular, 2.05, New	Domestic	Good	Does not dry in summer	0.88	6.80	35	Laterite. Unconfined.
19	Well on the left side of Honda-Dignem road about 50m away. Near Salgaonkar Mine, Kudne	Circular, 3.0, Old	Domestic	Good	Does not dry in summer	0.70	8.80	45	Laterite. Unconfined.
20	Well on the left side of the Sanqulim-Kudne road just side by the nala bridge	Rect., 3.76x1.8, Old	Domestic	Good	Does not dry in summer	0.87	6.60	10	Laterite. Unconfined.

Continued…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
21	Panchayat well near primary school and on the side of nala. Temple on opposite side of the nala	Circular, 2.9, Old	Domestic	Good	Does not dry in summer	0.65	4.90	12	Laterite. Unconfined.
22	Mr.Datta Hazari's well on the northern part of Kudne. Right side of the lane off the main road, near NW of temple	Square, 2x2, Old	Domestic	Good	Dries in summer	0.70	9.73	5	Laterite. Unconfined.
23	Panchayat well located on the right side of Kudne-Phal road, opposite side of primary school of Phal	Circular, 2.65, Old	Domestic	Turbid	Dries in summer	0.82	16.55	20	Laterite. Unconfined.
24	Private well on the left side of Kudne-Phal road	Circular, 2.0, 3 Yrs	Domestic	Good	Dries in summer	0.90	9.25	18	Laterite. Unconfined.
25	Panchayat well of Gavthan village located on the right side of Kudne -Sanquelim road on the north side of Kudne river	Circular, 2.1, 40 Yrs	Domestic	Good	Dries in summer	0.96	6.25	8	Laterite. Unconfined.
26	Mr. Hanumant Rao Desai's well located on right side of Gavthan-Sanquelim road near nala	Circular, 2.5, Old	Domestic	Good	Dries in summer	0.70	4.00	8	Laterite. Unconfined.
27	Temple well of Harvale near water fall	Circular, 2.43, Old	Domestic	Good	Does not dry in summer	0.67	10.43	60	Laterite. Unconfined.
28	Panchayat well located on the left side of road leading to Harvale fall and just before the rock caves on the side of nala	Circular, 2.95, Old	Domestic	Good	Does not dry in summer	0.65	6.87	38	Laterite. Unconfined.
29	Company well in Dabhalwado of Harvale on the left side of approach road to Wado about 200m from Harvale bus stop	Circular, 2.85, 20 Yrs	Domestic	Bad	Dries in summer	0.72	10.91	38	Laterite. Unconfined.
30	Panchayat well located right side of Sanquelim-Honda road and on the left side approach road from Harvale bus stop	Circular, 2.87, 30 Yrs	Domestic	Bad	Dries in summer	0.70	7.73	10	Laterite. Unconfined.

Continued…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
31	Mr. Jatobabu Pavne's well located on the left side of Valpoi road in the new settlement of Bhuipal village outskirts	Circular, 3.5, 22 Yrs	Domestic	Ok	Dries in summer	0.80	15.80	75	Laterite. Unconfined.
32	Well located in a form land compound on the left side of Valpoi-Honda road at Vadakade locality. Well is very close to nala and ACGL factory near Salili approach road	Circular, 4.96, Old	Irrigation	Good	Does not dry in summer	0.72	7.60	48	Laterite. Unconfined.
33	Mr. Rama Murthy's well located on the left side of Honda-Valpoi road, on the side of the nala at Vadakade locality	Circular, 3.5, 7 Yrs	Domestic	Good	Dries in summer	0.60	6.80	63	Laterite. Unconfined.
34	Mr. Yashwant Vithu Gavde's well located left side of Honda-Pissurle approach road, close to main road to Valpoi	Square, 2.37x2.37, 9 Yrs	Domestic	Good	Dries in summer	0.65	5.52	45	Laterite. Unconfined.
35	Panchayat well located on the left side of approach road in new settlement of Wagure village	Circular, 3.12, 20 Yrs	Domestic	Good	Dries in summer	0.72	17.18	74	Laterite. Unconfined.
36	Private well located in Pissurle village	Square, 1.98x1.98, Old	Domestic	Good	Dries in summer	0.82	6.30	50	Laterite. Unconfined.
37	Panchayat well located near school and left side of approach road from Pissurle-Kameri Khand	Circular, 3.15, 2 Yrs	Domestic	Turbid	Does not dry in summer	0.90	8.56	53	Laterite. Unconfined.
38	Panchayat well at Donkalwada (Avalmal) village located on the left side of Pissurle-Honda road	Circular, 4.8, 25 Yrs	Irrigation	Good	Dries in summer	0.82	5.32	42	Laterite. Unconfined.
39	Panchayat well located in Bandwada village on road side	Circular, 2.9, 15 Yrs	Domestic	Good	Dries in summer	0.72	7.50	48	Laterite. Unconfined.
40	Panchayat well located on the Dhatwada village	Circular, 2.64, 20 Yrs	Domestic	Good	Dries in summer	0.82	12.15	62	Laterite. Unconfined.

Continued…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
41	Panchayat well located on the edge of the flat valley in Dhonkalwada village	Square, 2.3x2.3, 90 Yrs	Domestic	Good	Dries in summer	0.80	4.68	45	Laterite. Unconfined.
42	Mr. Avinash's well located on the left side of Valpoi-Honda road in the autogarage compound near Honda panchayt	Circular, 4.2, 10 Yrs	Domestic	Good	Dries in summer	0.85	6.96	40	Laterite. Unconfined.
43	Panchayat well located on the right side of approach road to Han Solay village	Circular, 2.98, 12 Yrs	Domestic	Good	Does not dry in summer	0.82	6.58	42	Laterite. Unconfined.
44	Mr. Rama Mahadev Gavde's well located in the field on the left side of the road in Sonsi Village, nala is just 50m away from the well site	Square, 5.2x5.2, 20 Yrs	Domestic and Irrigation	Good	Does not dry in summer	0.50	7.26	58	Laterite. Unconfined.
45	Mr.Timlo Panduranga's well on the other side of the nala in Sonsi village, on left side of the mine road from Kudne to Pissurle	Circular, 3.24, 35 Yrs	Domestic	Good	Does not dry in summer	0.84	5.89	85	Laterite. Unconfined.
46	Mr. Sankhanath Hari's well behind his house at Digne village on the left side of Honda-Ponda road	Circular, 1.91, 50 Yrs	Domestic	Good	Dries in summer	0.83	9.28	125	Laterite. Unconfined.
47	Panchayat well Ovalayeh	Circular. 2.0, 15 Yrs	Domestic	Good	Does not dry in summer	1.00	5.77	65	Laterite. Unconfined.
48	Panchayat well Ovalayeh	Square, 5.5x5.5, Old	Domestic and Irrigation	Good	Does not dry in summer	0.00	5.95	74	Laterite. Unconfined.
49	Panchayat well Harvale	Circular, 2.9, Old	Domestic	Turbid	Does not dry in summer	1.05	10.05	52	Laterite. Unconfined.
50	Sri Vithoba Rukmini Temple well, Assnoda	Rectangr., 3.5x3.9, Very Old	Domestic	Good	Does not dry in summer	0.83	5.24	5.83	Laterite. Unconfined.

Continued…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
51	Temple well, Assnoda	Rectangr., 3.9x3.6, Old	Domestic	Good	Does not dry in summer	0.00	2.93	5.00	Laterite. Unconfined.
52	Public well, Assnoda	Rectangr., 1.6x1.75, Old	Domestic	Good	Does not dry in summer	0.30	3.63	5.30	Laterite. Unconfined.
53	Private well at Shirigao, infront of the temple	Old	Domestic	Good	Does not dry in summer	0.34	3.76	12.36	Laterite. Unconfined.
54	Public well, Manasbag, Mulagao	Rectangr., 3.55x3.72, Old	Domestic	Good	Does not dry in summer	0.57	3.73	8.57	Laterite. Unconfined.
55	Public well in Gaonkarwada at Mulagao	Rectangr., 1.91x1.92, Old	Domestic	Good	Does not dry in summer	0.54	7.47	8.54	Laterite. Unconfined.
56	Sri Prabhakar S. Saraph, Mulagao	Circular, 1.81, 1985	Domestic	Good	Dries in summer	0.71	3.21	6.71	Laterite. Unconfined.
57	Public well near ravalnath temple Pumphawada, Mulagao	Circular, 2.00, Old	Domestic	Good	Does not dry in summer	0.74	5.68	6.74	Laterite. Unconfined.
58	Public well Shivolkarwada Mulagao	Circular, 1.98, Old	Domestic	Good	Does not dry in summer	0.88	6.83	6.88	Laterite. Unconfined.
59	Private well at Borde Behind Sai Sagar hotel	Circular, 1.97, Old	Domestic	Good	Does not dry in summer	0.90	3.68	5.90	Laterite. Unconfined.
60	Sri Ravindra Gaothankar, Bordem	Circular, 2.05, 1990	Domestic	Good	Does not dry in summer	0.58	4.33	8.58	Laterite. Unconfined.

Continued…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
61	Sri F.S. Mujawar, Bordem	Circular, 1.73, New	Domestic	Good	Does not dry in summer	0.65	5.95	9.65	Laterite. Unconfined.
62	Sri Lakku Jaidevappa, Valshi	Circular, 1.90, Old	Domestic	Good	Does not dry in summer	0.90	10.63	5.90	Laterite. Unconfined.
63	Public well at Lamgao	Old	Domestic	Good	Dries in summer	0.92	8.98	15.92	Laterite. Unconfined.
64	Sri Chandrakanth J Manjrekar Of Bordem located in the farm house	Circular, 3.66, 1998	Domestic	Good	Does not dry in summer	0.75	24.51	32.75	Laterite. Unconfined.
65	Public well, Lakhira	Circular, 2.51, 1987	Domestic	Good	Dries in summer	0.84	17.03	45.94	Laterite. Unconfined.
66	Public well at Mavlinge	Circular, 2.35, Old	Domestic	Good	Does not dry in summer	0.85	5.77	50.85	Laterite. Unconfined.
67	Sri Rupesh Mayankar, behind temple Of Karbai at Kalbiwada	15 Yrs	Domestic	Good	Dries in summer	0.69	6.93	25.69	Laterite. Unconfined.
68	Sri Mahadev Gatti, Pira Road, Mayam	Circular, 1.04, Old	Domestic	Good	Does not dry in summer	0.81	6.43	8.81	Laterite. Unconfined.
69	Temple well, Gaonkarwada on Mayam- Paira Road	Circular, 1.03,	Domestic	Good	Does not dry in summer	0.42	7.23	8.42	Laterite. Unconfined.
70	Sri Kalsadatta temple well, Paira	Circular, 1.40, Old	Domestic	Good	Does not dry in summer	0.76	9.86	10.76	Laterite. Unconfined.

Continues…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
71	Public well located near Raskali Devasthan at Shikeri	Circular, 1.40, Old	Domestic	Good	Does not dry in summer	0.77	6.74	9.77	Laterite. Unconfined.
72	Public well at Haldanwadi, Mayam	Circular, 1.41, Old	Domestic	Good	Dries in summer	0.81	5.51	6.81	Laterite. Unconfined.
73	Private well at Kumbarwada, Mayam	Circular, 1.39, Old	Domestic	Good	Dries in summer	0.70	4.01	10.70	Laterite. Unconfined.
74	Public well at Panolen	Circular, 2.00, Old	Domestic	Good	Does not dry in summer	0.74	6.93	5.74	Laterite. Unconfined.
75	Private well at Kelvi	Old	Domestic	Good	Does not dry in summer	0.62	6.60	5.62	Laterite. Unconfined.
76	Private well at Aturli, Mayam (varpal)	Circular, 1.84, Old	Domestic	Good	Does not dry in summer	0.77	5.80	45.77	Laterite. Unconfined.
77	Public well at Tikasan close agri land	Circular, 1.78, Old	Domestic	Good	Does not dry in summer	0.86	3.56	5.86	Laterite. Unconfined.
78	Sri Khetoba temple well, Vaingunem	Circular, 1.16,	Domestic	Good	Does not dry in summer	1.08	6.25	6.08	Laterite. Unconfined.
79	Private well at Aturli	Circular, 2.50, Old	Domestic	Good	Does not dry in summer	0.88	5.50	5.88	Laterite. Unconfined.
80	Sri Shantadurga temple well, Narve	Circular, 2.36, Very Old	Domestic	Good	Does not dry in summer	0.78	16.66	40.78	Laterite. Unconfined.

Continues…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
81	Sri Shantadurga temple well at Narve	Circular, 1.90, Very Old	Domestic	Good	Does not dry in summer	0.85	9.13	58.89	Laterite. Unconfined.
82	Temple well at Piligao	Circular, 1.28, Old	Domestic	Good	Does not dry in summer	0.63	6.01	20.63	Laterite. Unconfined.
83	Private well at Bicholim, close to Dempo mine	Circular, 0.92, Old	Domestic	Good	Does not dry in summer	0.72	7.74	18.72	Laterite. Unconfined.
84	Public well at Dhabdaba	Old	Domestic	Good	Dries in summer	0.86	6.62	18.86	Laterite. Unconfined.
85	Public well at Bicholim before the Hospital	Circular, 2.41, Very Old	Domestic	Good	Does not dry in summer	0.88	10.13	8.88	Laterite. Unconfined.
86	Private well at sarvoan	Circular, 1.35, 1998	Domestic	Good	Does not dry in summer	0.91	7.92	5.91	Laterite. Unconfined.
87	Public well at Sarovan infront of Sri Nakul's house	Circular, 2.96, Old	Domestic	Good	Does not dry in summer	1.12	5.04	13.12	Laterite. Unconfined.
88	Sri Shantadurga temple well, karapur	Circular, 2.05, Very Old	Domestic	Good	Does not dry in summer	0.72	5.08	5.76	Laterite. Unconfined.
89	Private well, karapur (Only one house)	Circular, 2.17,	Domestic	Good	Does not dry in summer	1.39	6.83	4.39	Laterite. Unconfined.
90	Public well at Ghadiwada	Circular, 1.21, Old	Domestic	Good	Does not dry in summer	1.12	8.35	6.12	Laterite. Unconfined.

Continues…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
91	Temple well at Virdi	Circular, 1.94, Old	Domestic	Good	Does not dry in summer	1.01	4.71	11.01	Laterite. Unconfined.
92	Private well at Kharekhazan, Virdi	Circular, 2.30, Old	Domestic	Good	Does not dry in summer	0.78	12.28	3.78	Laterite. Unconfined.
93	Well of Forest Dept., at Morle	Circular, 2.84, Old	Domestic	Good	Does not dry in summer	0.69	6.00	39.69	Laterite. Unconfined.
94	Public well at Gothle	Circular, 2.68, Old	Domestic	Good	Does not dry in summer	0.74	7.85	65.74	Laterite. Unconfined.
95	Private well at Datwada(Bagwada)	Circular, 3.32,	Domestic	Good	Dries in summer	0.75	7.33	10.75	Laterite. Unconfined.
96	Public well at Bagwada	Circular, 1.24, Old	Domestic	Good	Does not dry in summer	0.89	4.90	8.89	Laterite. Unconfined.
97	Public well at matwada	Circular, 2.30, Old	Domestic	Good	Does not dry in summer	1.86	6.43	6.89	Laterite. Unconfined.
98	Public well at sarmona	Circular, 1.39, Very Old	Domestic	Saline	Does not dry in summer	0.35	3.90	5.35	Laterite. Unconfined.

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Note: All the observation wells are open dug wells. The age of well and water quality data was recorded from enquiries from the well users and well owners.

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
99(1)	Panchayat well. Kudne.	Rectangular 2.25x1.85 Old	Domestic	Good	Does not dry in summer	0.77	5.58	8.77	Laterite. Unconfined.
100(2)	Panchayat well. Phal.	Circular, 1.30 Old	Domestic	Good	Does not dry in summer	1.17	8.33	13.67	Laterite. Unconfined
101(3)	Panchayat well. Chikne.	Circular, 1.03 Old	Domestic	Good	Does not dry in summer	0.84	6.52	12.34	Laterite. Unconfined.
102(4)	Shankar Hazare. Digne.	Circular, 0.99 Old	Domestic	Good	Does not dry in summer	0.88	8.13	35.88	Laterite. Unconfined.
103(5)	Kishore .R. Barve. Surla.[Behind post office.]	Circular, 1.15 Old	Domestic	Good	Does not dry in summer	0.62	13.89	70.62	Laterite. Unconfined.
104(6)	Narayan Paliekar. H.NO.-322-2. Vlguem.	Circular, 0.97 Old	Domestic	Good	Does not dry in summer	0.56	7.61	38.56	Laterite. Unconfined.
105(7)	Urmila Bhaskar Gadgil. Kadsal.	Square. 3.10 Very old	Domestic	Good	Does not dry in summer	0.23	9.93	39.23	Laterite. Unconfined.
106(8)	Shiva Malik. Satichewad Kudne.	Circular, 1.10 New	Domestic	Good	Does not dry in summer	0.74	7.43	14.24	Laterite. Unconfined.
107(9)	Panchayat well. Bernawada- Naveli.	Circular, 0.81 Old	Domestic	Good	Does not dry in summer	0.77	3.08	7.77	Laterite. Unconfined.
108(10)	Arun Shetye. Pajerwada Surla.	Rectangular 1.58x1.42 Old	Domestic	Good	Does not dry in summer	0.95	5.14	30.95	Laterite. Unconfined.

Contd…

Well No.	Well Owner & Location	Well type, radius (m) & Age	Well Use	Water Quality	Summer Water Levels	M.P. ht. a.grd (m)	Well depth b. MP (m)	MP ht. amsl m)	Geology Aquifer
109(11)	Anand Rama Kavlekar. Gutkatad Surla.	Circular, 1.22 Old	Domestic	Good	Does not dry in summer	0.43	3.75	14.43	Laterite. Unconfined.
110(12)	Panchayat well. Kothambi.	Circular, 1.27 Old	Domestic	Good	Does not dry in summer	1	6.01	22	Laterite. Unconfined.
111(13)	Panchayat well. Tada- Pale.	Circular, 1.69 Old	Domestic	Good	Does not dry in summer	0.74	6.21	16.74	Laterite. Unconfined.
112(14)	Uday Surlakar. Ghadiwada Surla.	Circular 0.93 Old	Domestic	Good	Does not dry in summer	0.39	5.27	20.89	Laterite. Unconfined.
113(15)	Phodu Krishna Bhanaikar. Baya Surla.	Circular, 0.95 Old	Domestic	Good	Does not dry in summer	0.83	6.82	29.83	Laterite. Unconfined.
114(16)	Panchayat well. Near Ganesh Temple. Velguem.	Rectangular 2.82x2.87 Old	Domestic	Good	Does not dry in summer	0.68	12.63	40.68	Laterite. Unconfined.
115(17)	Panchayat well. Kudne.	Circular, 2.06 Nev	Domestic	Good	Does not dry in summer	1.1	1.42	11.1	Laterite. Unconfined.
116(118)	Panchayat well. Tishe.	Circular. 0.94 Old	Domestic	Good	Does not dry in summer	0.8	9.13	40.8	Laterite. Unconfined.

Table 2: Monthly groundwater level data in the mining belts of North Goa

Well No.	MP.ht agl (m)	Depth to water levels below Measuring Point in meters											
		Dec. 02	**Jan.03**	**Feb. 03**	**Mar.03**	**Apr.03**	**May.03**	**Jun.03**	**Jul.03**	**Aug.03**	**Sep.03**	**Oct.03**	**Nov.03**
1	0.80	7.56	7.89	8.50	9.05	9.71	2.90	2.82	4.41	3.99	5.17	6.00	6.67
2	0.90	6.47	6.92	7.93	8.84	9.89	7.07	6.58	2.69	2.29	3.63	5.17	5.98
3	0.65	4.70	4.93	5.22	5.49	5.92	4.94	4.81	2.98	2.82	3.26	3.99	4.38
4	0.94	2.15	2.40	2.73	3.08	3.17	2.17	2.54	1.11	1.05	1.42	1.72	1.98
5	0.60	2.94	3.18	3.52	3.75	3.76	3.17	3.29	2.45	2.16	2.31	2.47	2.75
6	0.50	2.94	2.99	3.22	3.86	5.36	3.90	4.21	1.58	1.67	2.06	2.29	2.61
7	0.40	6.03	6.30	6.62	7.54	8.62	7.11	6.19	3.90	3.18	4.07	4.62	5.50
8	0.50	3.72	3.95	4.13	4.31	4.73	3.90	3.61	1.92	2.07	2.48	3.02	3.31
9	0.70	8.06	8.15	8.15	8.20	7.43	7.58	6.80	5.07	5.87	6.30	6.96	7.84
10	0.75	4.27	4.35	4.64	4.69	4.58	4.58	4.06	2.95	1.85	3.07	3.68	4.04
11	0.70	4.19	4.16	4.43	4.49	4.48	4.04	4.57	3.29	3.14	3.51	3.99	4.25
12	0.82	5.54	5.44	5.62	5.65	5.82	5.30	5.64	4.19	3.98	4.39	4.81	5.26
13	0.60	9.25	9.40	9.62	9.81	7.04	9.94	6.43	4.10	3.77	6.52	6.72	8.83
14	0.65	3.88	3.91	4.07	4.33	4.51	3.76	4.39	2.64	2.63	2.98	3.27	3.73
15	0.70	7.74	7.79	8.10	8.36	8.38	7.96	6.32	5.20	4.32	5.70	5.95	7.22
16	0.60	7.35	7.25	7.26	7.56	7.49	4.78	4.58	1.94	1.59	3.82	5.38	6.70
17	0.80	3.15	3.15	3.48	4.11	4.27	3.00	2.38	1.97	1.75	2.43	2.79	2.94

Continued…

Note: During 2003 the first rain started on 9th of June 2003 and the water levels were recorded on 21st of June. Therefore one can compute the areas of quick recharge by plotting the contours of water level magnitude rise during this period of 12 days.

Well No.	MP.ht agl (m)	Depth to water levels below Measuring Point in meters											
		Dec. 02	**Jan.03**	**Feb. 03**	**Mar.03**	**Apr.03**	**May.03**	**Jun.03**	**Jul.03**	**Aug.03**	**Sep.03**	**Oct.03**	**Nov.03**
18	0.88	5.76	5.99	6.14	6.44	6.36	5.42	4.86	3.60	3.62	3.99	4.67	5.44
19	0.70	4.05	4.44	5.13	6.20	6.08	3.69	3.64	2.36	2.25	2.71	3.36	3.72
20	0.87	5.28	5.40	5.45	5.49	5.78	4.88	3.96	3.71	4.08	4.19	5.18	5.11
21	0.65	4.40	4.35	4.44	4.47	4.65	4.00	4.74	2.67	2.57	3.32	3.89	4.13
22	0.70	9.19	9.29	9.04	9.47	9.61	8.87	6.60	6.93	7.09	7.82	8.10	9.03
23	0.82	14.20	14.92	14.95	15.29	14.79	14.77	10.21	10.27	9.33	11.70	10.86	12.59
24	0.90	8.87	9.03	8.58	9.19	9.28	8.51	5.98	5.97	6.20	7.25	7.03	8.24
25	0.96	5.75	5.60	5.92	5.95	5.94	5.35	4.31	4.02	3.94	4.28	4.32	5.34
26	0.70	2.36	2.57	2.76	3.11	3.28	2.79	2.33	1.86	1.83	1.86	1.94	2.15
27	0.67	9.78	9.94	9.87	8.49	8.80	8.93	8.17	8.50	7.96	7.86	8.19	9.42
28	0.65	5.73	5.74	5.83	6.39	6.19	5.44	4.90	4.60	4.54	4.71	5.06	5.52
29	0.72	9.52	9.66	9.94	10.23	10.00	8.79	7.88	7.52	7.24	7.64	7.90	8.73
30	0.70	6.70	6.80	6.98	6.30	7.06	6.36	5.57	4.95	5.13	5.49	5.70	5.85
31	0.80	14.25	14.66	14.78	15.34	15.55	6.15	7.11	8.97	8.99	9.82	10.28	13.70
32	0.72	4.71	4.38	4.38	4.88	4.89	4.19	4.10	3.07	2.88	3.34	3.60	3.88
33	0.60	3.84	4.12	4.34	4.51	5.60	4.58	3.99	2.41	2.01	2.76	3.66	3.80
34	0.65	4.46	4.58	4.80	5.03	5.07	3.39	3.55	2.87	2.80	3.49	3.82	4.03

Continued…

Well No.	MP.ht agl (m)	Depth to water levels below Measuring Point in meters											
		Dec. 02	**Jan.03**	**Feb. 03**	**Mar.03**	**Apr.03**	**May.03**	**Jun.03**	**Jul.03**	**Aug.03**	**Sep.03**	**Oct.03**	**Nov.03**
35	0.72	11.09	12.76	13.46	14.35	15.49	11.45	7.57	2.69	2.52	4.88	5.18	7.95
36	0.82	3.92	3.96	4.38	4.75	6.11	4.71	5.15	2.41	2.38	2.76	3.76	3.82
37	0.90	6.07	6.57	7.38	7.46	7.55	5.41	4.39	2.72	2.88	3.98	4.50	5.38
38	0.82	4.52	5.23	4.46	4.84	4.71	3.99	2.98	2.35	2.50	3.27	4.10	4.21
39	0.72	6.50	6.91	6.98	7.30	7.85	dry	3.70	4.70	5.07	6.03	6.11	6.36
40	0.82	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
41	0.80	3.26	2.88	3.43	3.76	4.08	3.45	3.33	2.04	2.05	2.29	3.02	2.97
42	0.85	6.10	6.54	6.61	6.58	6.65	6.25	5.64	4.97	4.43	5.11	5.11	5.61
43	0.82	5.56	5.62	6.32	6.06	6.21	5.16	4.72	2.67	2.61	3.16	3.45	4.54
44	0.50	4.65	4.74	4.99	5.11	5.42	4.66	4.30	3.15	2.88	3.42	3.87	4.30
45	0.84	4.12	4.64	4.77	5.10	5.29	4.42	3.90	2.95	2.44	3.27	3.22	3.77
46	0.83	7.53	7.72	8.27	8.34	8.81	7.81	6.87	5.62	5.49	5.95	5.91	7.29
47	1.00	3.48	3.43	3.60	3.95	4.72	3.80	3.46	2.25	2.43	3.60	3.23	3.29
48	0.00	3.84	3.53	3.82	4.20	4.82	4.42	3.57	1.91	1.76	2.55	3.51	3.67
49	0.05	8.05	8.72	8.97	9.26	9.53	8.56	7.76	6.08	5.85	6.89	6.72	7.21

Continued…

Well No.	MP.ht agl (m)	Depth to water levels below Measuring Point in meters											
		Dec. 02	**Jan.03**	**Feb. 03**	**Mar.03**	**Apr.03**	**May.03**	**Jun.03**	**Jul.03**	**Aug.03**	**Sep.03**	**Oct.03**	**Nov.03**
50	5.83	3.58	3.57	3.55	3.57	3.72	4.03	2.19	2.55	3.12	2.44	3.54	3.60
51	5.00	0.81	0.98	0.84	0.87	1.44	1.56	0.23	0.36	0.61	0.77	0.81	0.75
52	5.30	2.03	2.25	2.29	2.27	2.22	2.19	0.25	0.46	0.87	1.50	1.73	1.91
53	12.36	2.56	2.66	2.72	2.70	3.75	3.23	2.13	2.13	2.39	2.66	3.02	2.96
54	8.57	2.42	2.50	2.62	2.55	2.66	2.76	1.52	1.55	1.6	1.93	2.62	2.55
55	8.54	3.42	3.06	3.05	3.35	3.12	3.12	1.64	2.60	3.03	3.28	3.27	4.00
56	6.71	2.13	2.34	2.32	2.47	2.87	3.03	1.19	1.59	1.75	2.02	2.00	2.16
57	6.74	4.05	4.33	4.41	4.51	4.97	5.02	2.98	3.57	3.85	3.90	3.92	3.95
58	6.88	5.85	6.03	6.23	6.35	6.62	6.80	2.85	2.87	3.76	4.83	5.27	5.68
59	5.90	2.83	2.93	3.10	3.18	3.28	3.26	1.17	1.41	1.71	2.08	2.30	2.53
60	8.58	3.23	3.42	3.58	3.71	3.88	3.96	1.84	1.92	1.45	2.30	2.76	3.05
61	9.65	5.42	5.50	5.55	5.62	5.71	5.75	1.33	1.65	3.39	4.47	4.97	5.25
62	5.90	8.36	8.31	7.78	8.57	9.35	9.48	5.73	6.59	6.85	7.20	7.13	7.42
63	15.92	6.78	6.90	7.09	7.19	8.72	8.57	3.51	3.39	5.0	5.60	5.53	6.00
64	32.75	22.83	22.99	23.74	23.73	23.49	23.50	22.96	17.92	20.02	21.75	21.73	22.73
65	45.94	13.80	14.73	14.80	15.19	19.87	16.91	7.52	5.92	9.28	11.95	12.91	13.64
66	50.85	3.88	4.44	4.94	5.13	5.37	5.48	1.66	1.72	2.04	2.23	2.13	3.27

Continued…

Well No.	MP.ht agl (m)	Depth to water levels below Measuring Point in meters											
		Dec. 02	Jan.03	Feb. 03	Mar.03	Apr.03	May.03	Jun.03	Jul.03	Aug.03	Sep.03	Oct.03	Nov.03
67	25.69	5.96	6.02	5.98	6.21	6.40	6.69	3.53	3.64	4.60	5.46	5.40	5.73
68	8.81	5.28	5.27	5.54	5.77	6.15	6.39	3.77	4.09	4.57	4.88	4.80	5.06
69	8.42	6.03	6.08	6.16	6.16	6.22	6.49	4.94	5.30	5.60	5.75	7.28	5.78
70	10.76	9.07	9.83	9.40	9.49	9.41	9.62	6.29	6.82	7.46	8.03	7.88	8.79
71	9.77	5.78	6.00	6.30	6.38	6.42	6.49	4.00	4.51	4.85	5.02	5.23	5.49
72	6.81	3.48	3.61	4.15	4.38	5.00	4.99	1.83	2.43	2.80	3.01	2.96	3.13
73	10.70	3.41	3.46	3.46	3.54	3.71	3.87	0.93	1.56	2.49	3.03	2.88	3.10
74	5.74	5.45	5.60	5.51	5.43	5.51	5.65	4.28	4.76	4.99	5.22	5.14	5.26
75	5.62	5.72	5.82	5.81	5.77	Inacce.	Inacce.	Inacce.	Inacce.	Inacce.	Inacce.	Inacce.	Inacce.
76	45.77	4.01	3.97	4.10	4.22	5.23	5.15	2.97	3.22	3.64	3.79	3.76	3.87
77	5.86	2.67	2.69	2.74	3.06	2.91	2.98	1.00	1.02	1.78	2.26	2.2	2.50
78	6.08	5.54	5.58	5.73	6.11	5.70	6.06	2.85	2.75	4.07	4.82	4.76	5.14
79	5.88	3.70	3.73	3.86	3.84	4.02	4.53	1.95	2.01	2.80	3.37	3.34	3.43
80	40.78	15.60	15.70	15.81	15.88	16.27	16.32	11.34	12.18	14.03	14.95	14.92	15.10
81	58.89	8.53	8.57	8.65	8.71	8.81	8.73	5.47	5.94	6.43	7.54	7.46	8.17
82	20.63	1.53	2.53	4.12	5.13	Dry	Dry	0.89	10.15	1.23	1.43	1.38	1.37
83	18.72	6.92	6.99	7.50	7.77	7.97	7.86	5.94	5.95	6.05	6.17	5.72	5.83

Continued…

Well No.	MP.ht agl (m)	Depth to water levels below Measuring Point in meters											
		Dec. 02	**Jan.03**	**Feb. 03**	**Mar.03**	**Apr.03**	**May.03**	**Jun.03**	**Jul.03**	**Aug.03**	**Sep.03**	**Oct.03**	**Nov.03**
84	18.86	6.09	6.24	6.22	6.13	5.41	6.58	4.02	4.51	5.07	5.40	5.36	5.79
85	8.88	9.47	9.63	8.93	8.98	8.96	9.04	4.65	3.99	4.99	6.96	8.37	8.71
86	5.91	7.32	7.36	7.42	7.34	7.46	7.45	5.66	5.57	6.50	7.10	7.23	7.28
87	13.12	4.29	4.50	4.96	3.93	4.79	4.68	2.40	2.45	3.16	3.46	3.91	4.04
88	5.76	4.05	4.19	3.91	3.99	3.98	4.22	1.60	2.24	2.87	3.66	3.42	3.57
89	4.39	4.75	4.87	4.84	4.94	5.64	5.67	2.88	3.26	3.94	4.46	4.69	4.63
90	6.12	7.08	7.31	7.40	7.46	7.63	7.75	4.51	5.70	6.12	6.64	6.88	6.91
91	11.01	3.83	3.91	3.88	3.89	4.01	4.23	2.02	2.53	2.97	3.50	3.66	3.69
92	3.78	11.83	11.88	11.91	11.86	11.93	12.13	9.07	10.22	10.72	11.28	11.75	11.73
93	39.69	4.59	4.41	4.42	4.40	4.47	4.56	3.41	3.56	3.86	4.42	4.36	4.59
94	65.74	3.44	3.45	3.85	3.96	3.93	3.58	2.11	2.73	3.33	3.90	3.88	3.43
95	10.75	5.28	5.56	6.01	5.91	6.11	6.05	2.40	2.32	3.85	4.29	4.25	4.89
96	8.89	3.47	3.69	3.57	3.39	3.67	3.85	1.84	2.54	2.98	3.27	3.13	3.37
97	6.89	2.11	2.35	3.24	3.85	5.22	6.35	1.90	1.91	1.91	1.94	1.91	2.01
98	5.35	2.03	2.23	2.11	2.17	2.40	1.45	0.50	1.28	1.43	1.85	1.81	2.10

Continued…

Well No.	MP.ht agl (m)	Depth to water levels below Measuring Point in meters											
		Dec. 02	Jan.03	Feb. 03	Mar.03	Apr.03	May.03	Jun.03	Jul.03	Aug.03	Sep.03	Oct.03	Nov.03
1-99	0.77	NA	NA	NA	5.28	3.97	4.56	4.75	5.06	5.22	5.12	3.97	4.56
2-100	1.17	NA	NA	NA	8.33	6.58	7.09	7.44	7.68	7.85	7.97	6.58	7.09
3-101	0.84	NA	NA	NA	6.52	4.85	4	5.28	5.91	6.13	6.2	4.85	4.00
4-102	0.88	NA	NA	NA	8.13	6.02	6.11	7.15	7.38	7.49	7.59	6.02	6.11
5-103	0.62	NA	NA	NA	13.89	10.38	11.6	11.92	12.14	12.43	11.29	10.38	11.6
6-104	0.56	NA	NA	NA	7.61	3.58	3.83	4.84	5.61	6.28	6.93	3.58	3.83
7-105	0.23	NA	NA	NA	9.93	4.48	5.84	6.53	7.89	9.18	8.66	4.48	5.84
8-106	0.74	NA	NA	NA	7.43	4.95	5.63	6.22	6.72	6.99	7.13	4.95	5.63
9-107	0.77	NA	NA	NA	3.08	1.9	2.32	2.35	2.58	2.68	2.79	1.9	2.32
10-108	0.95	NA	NA	NA	5.14	4.07	4.51	4.73	4.83	4.98	4.97	4.07	4.51
11-109	0.43	NA	NA	NA	3.75	1.16	1.82	2.63	3.08	3.72	3.8	1.16	1.82
12-110	1.00	NA	NA	NA	6.01	3.98	4.83	5.31	5.49	5.93	5.95	3.98	4.83
13-111	0.74	NA	NA	NA	6.21	3.51	5.04	5.1	4.93	4.75	5.19	3.51	5.04
14-112	0.39	NA	NA	NA	5.27	2.81	2.97	3.1	3.3	3.86	4.09	2.81	2.97
15-113	0.83	NA	NA	NA	6.82	4.71	5.36	5.6	5.88	6.25	6.5	4.71	5.36
16-114	0.68	NA	NA	NA	12.63	7.87	8.56	9.93	10.92	12.03	12.12	7.87	8.56
17-115	1.10	NA	NA	NA	1.42	.93	0.88	1.02	1.1	0.95	1.2	.93	0.88
18-116	0.80	NA	NA	NA	9.13	5.56	6.83	8.02	8.28	8.26	8.56	5.56	6.83

CORRELATION STUDIES BETWEEN DRAINAGE DENSITY AND GROUNDWATER RECHARGE IN THE TEN MINING WATERSHEDS ON NORTH GOA

Drainage density:

Drainage density (Dd), is regarded as the most important aerial measure of network geometry of surface streams, in that it expresses the degree of basin dissection by surface streams and hence links the form attributes of the basin to underlying processes and is defined by;

$$\mathbf{Dd} = \frac{\Sigma L}{A_d}$$

Where Σ L is the total channel length in the basin of area A_d,
Or is also written as,

$$\textbf{Drainage density} = \frac{\textbf{Total lengths of streams (miles)}}{\textbf{Area (square miles)}}$$

Two sets of factors determine drainage density: those which govern the amount and quality of water received at the surface, and those which control the subsequent distribution of that water, its availability for channel cutting, and erodibility. The first is climatic, while the second includes a complex mix of litologic, vegetation, and edaphic and topographic influences. Drainage density is broadly correlated with mean annual precipitation.

There are various factors that control the drainage density. One highly important control is rock type. Hard, resistant rocks such as intrusive granitic rock, gneiss, sandstone, and quartzite, tend to give low drainage density (course texture). This is because stream erosion is difficult and only a relatively large channel can maintain itself. A second factor is the relative ease of infiltration of precipitation into the ground surface and downward to the water table. Highly permeable materials, such as sand or gravel, tend to give low drainage density because infiltration is large and little water is available as surface runoff to maintain channels. Clays and shale, on the other hand, have a high proportion of surface runoff and this combines with their weakness to give high drainage density. A third major factor is the presence or absence of vegetative cover. A weak rock will have much lower drainage density in a humid climate, where a strong, dense cover of forest or grass protects the underlying material, than in an arid region where no protective cover exists.

In the present study an attempt has been made to find a correlation between the drainage density and the rainfall recharge if any. To do this at first the drainage density has been calculated by using 1km^2 grid network on the map. These drainage density values were used to plot the contour map of drainage density variation in the study area as shown in Figs DD1 to DD10. The water table fluctuation map for 2003 is also shown in the same figures for the corresponding area. It was found that there is a correlation between the drainage density and rainfall recharge i.e. lower drainage density areas coincide with higher rainfall recharge (large water table fluctuation) and this further indicates that the low drainage density in that particular area is due to presence of permeable soil layer at the surface and not due to impervious rocks which also can give rise to low drainage density.

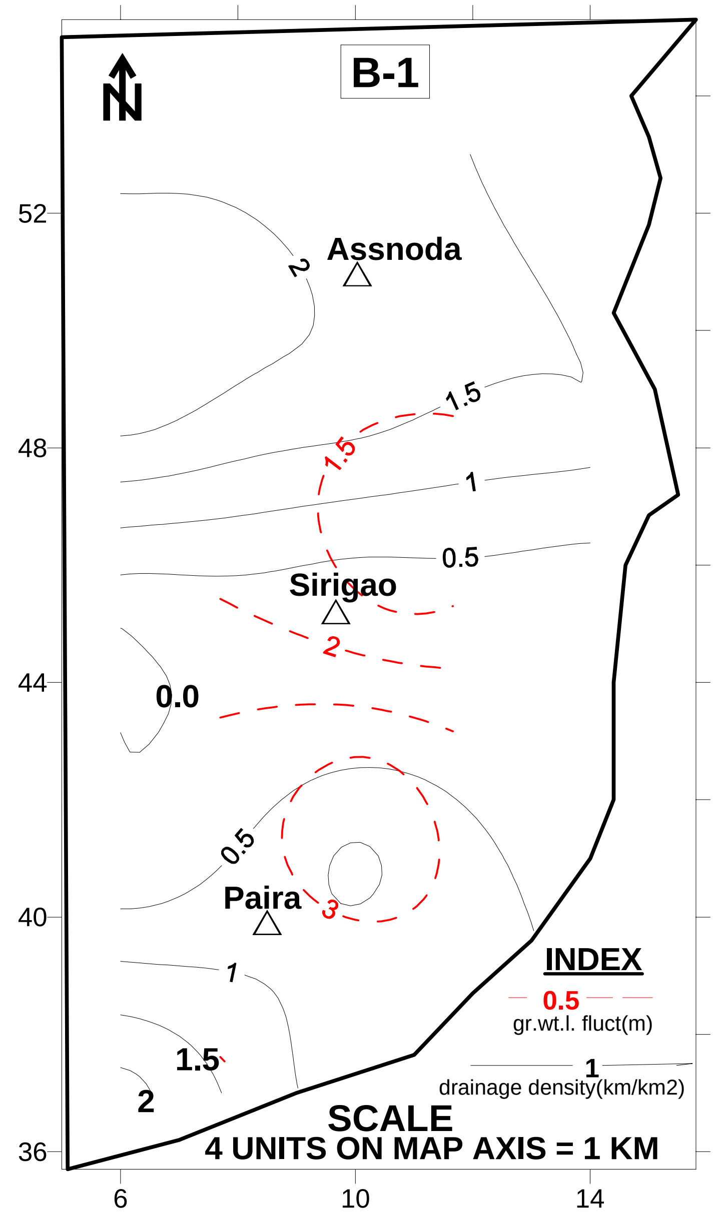


Fig.DD 1:Drainage density and groundwater recharge relation at B-1

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 391hacteres
2. Villages: Sirigao
3. Land use (in ha): Agriculture (107), Barren/fallow/degraded/waste land (52), Mine pits (52), Barren dumps (89), Vegetated dumps (57), Wetlands (34).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

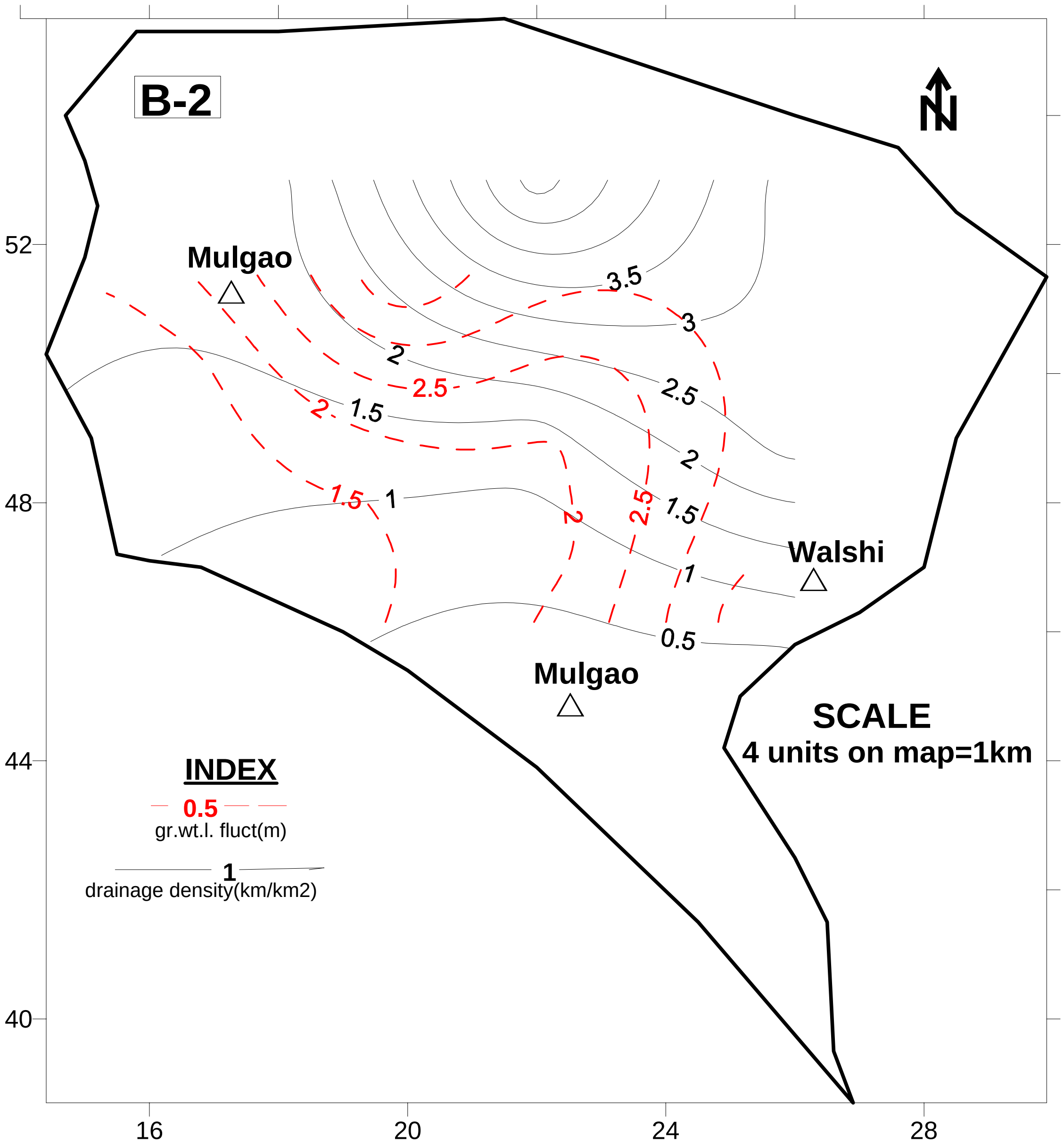


Fig.DD 2: Drainage density and groundwater recharge relation at B-2

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 862 hactares
2. Villages: Mulgao, Lamgao
3. Land use (in ha): Agriculture (511), Barren/fallow/degraded/waste land (225), Mine pits (68), Vegetated dumps (51), Water bodies (7).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

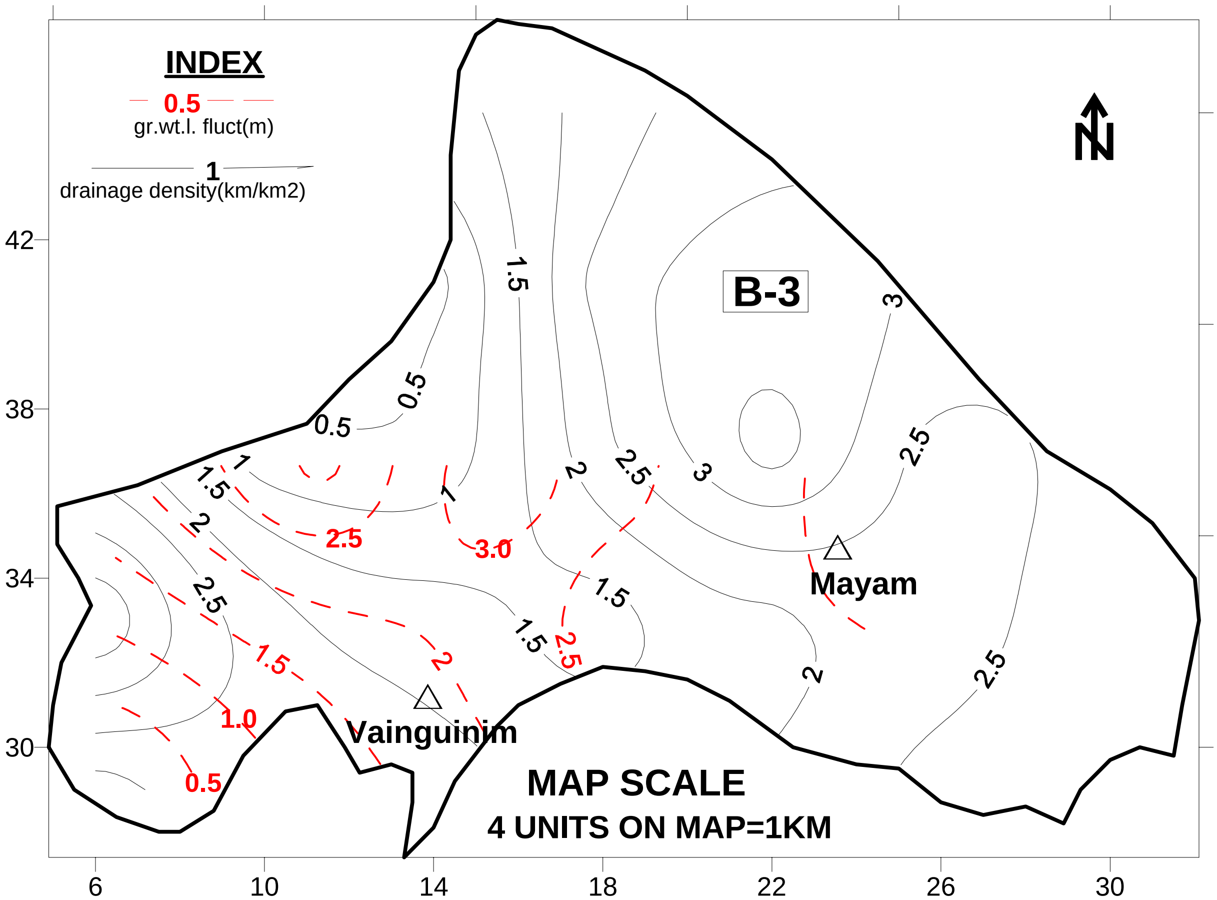


Fig.DD 3: Drainage density and groundwater recharge relation at B-3

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 1920 hacteres
2. Villages: Mayem, Lamgao, and Vainguinim
3. Land use (in ha): Agriculture (1082), Builtup/Industrial/hard surfaces (67), Barren/fallow/degraded/waste land (210), Mine pits (134), Barren dumps (76), Vegetated dumps (35), Wetlands (160), Water bodies (157).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

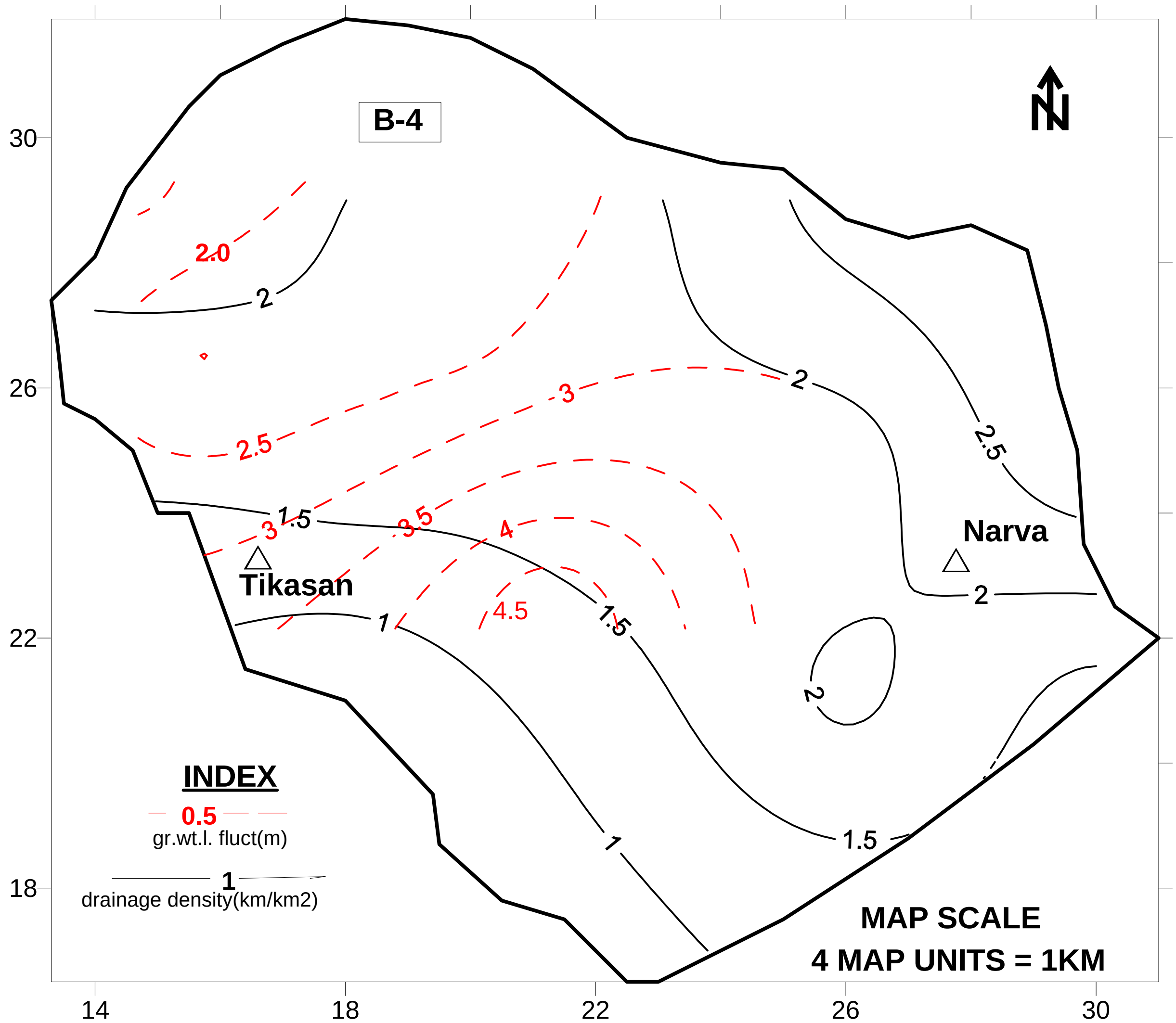


Fig.DD 4: Drainage density and groundwater recharge relation at B-4

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 1172 hacteres
2. Villages: Aturli and Narova
3. Land use (in ha): Agriculture (782), Builtup/Industrial/hard surfaces (53), Barren/fallow/degraded/waste land (150), Water bodies (187).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

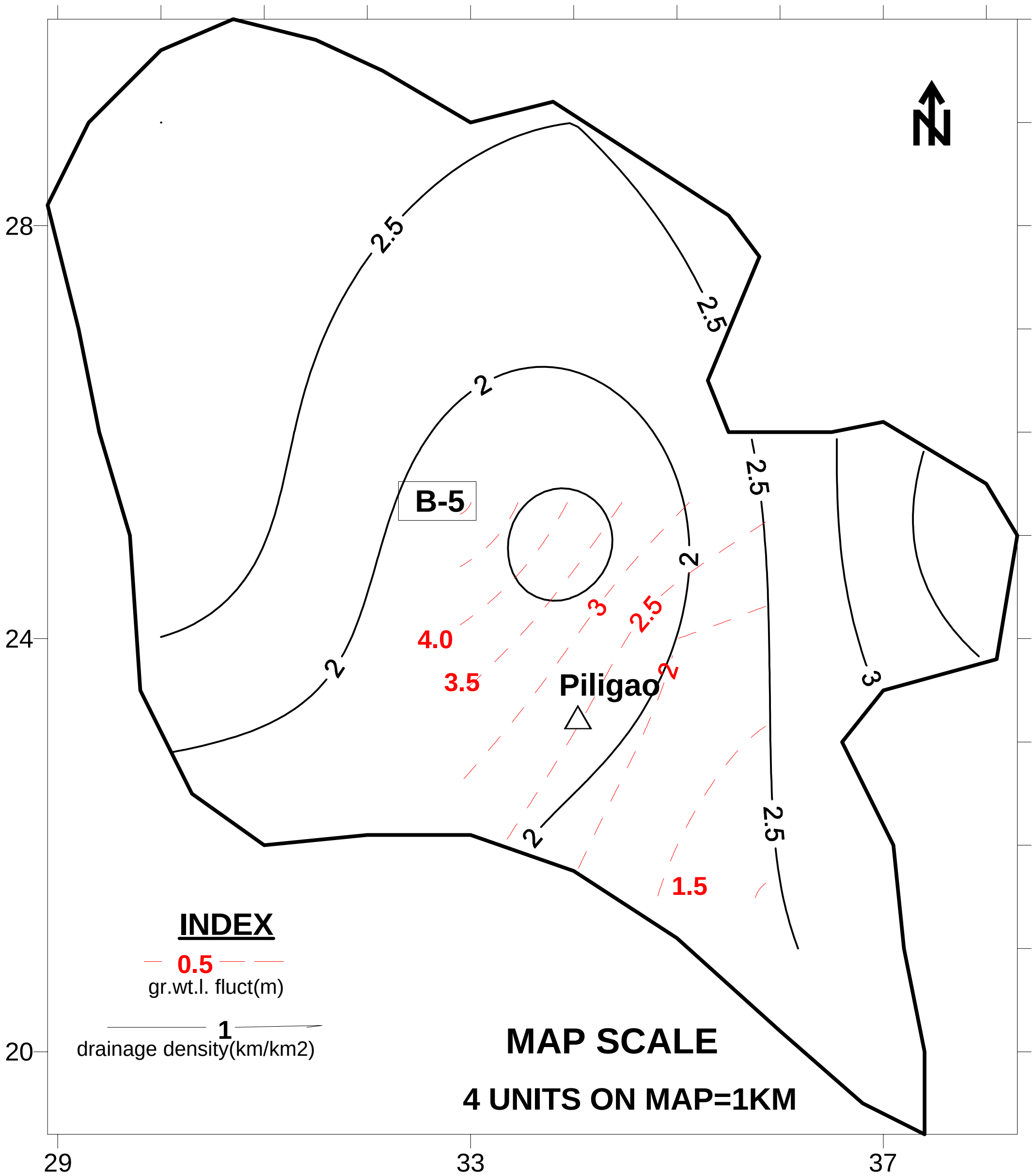


Fig. DD 5: Drainage density and groundwater recharge relation at B-5

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 400 hacteres
2. Villages: Piligao
3. Land use (in ha): Agriculture (231), Barren/fallow/degraded/waste land (92), Water bodies (76).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

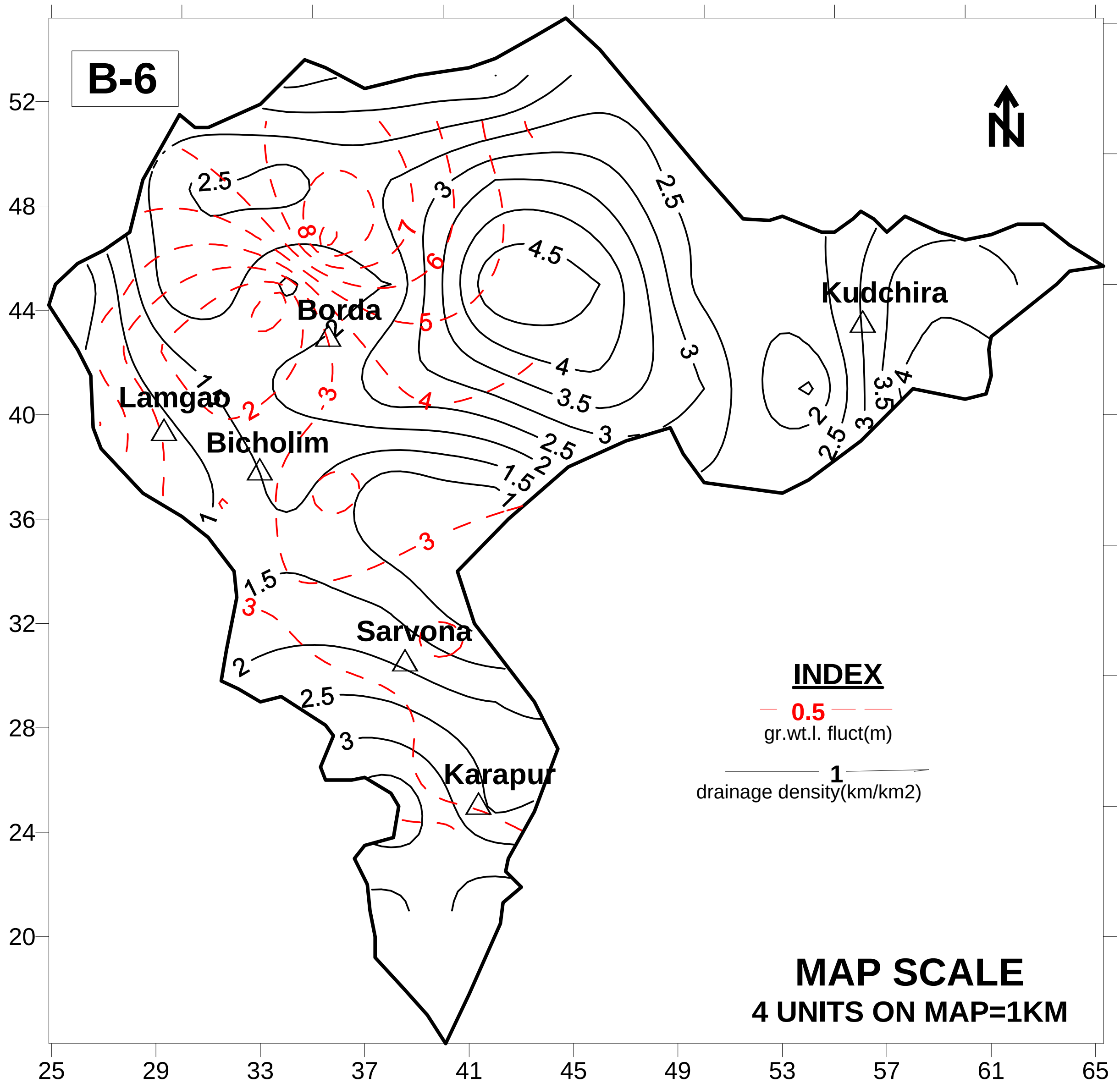


Fig. DD 6: Drainage density and groundwater recharge relation at B-6

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 3778 hacteres
2. Villages: Lamgao, Ona, Bicholim, Sarvona and Cudchairem
3. Land use (in ha): Agriculture (1997), Builtup/Industrial/hard surfaces (255), Pastures/grass land/open shrubs (960), Barren/fallow/degraded/waste land (412), Mine pits (58), Wetlands (47), Water bodies (49).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

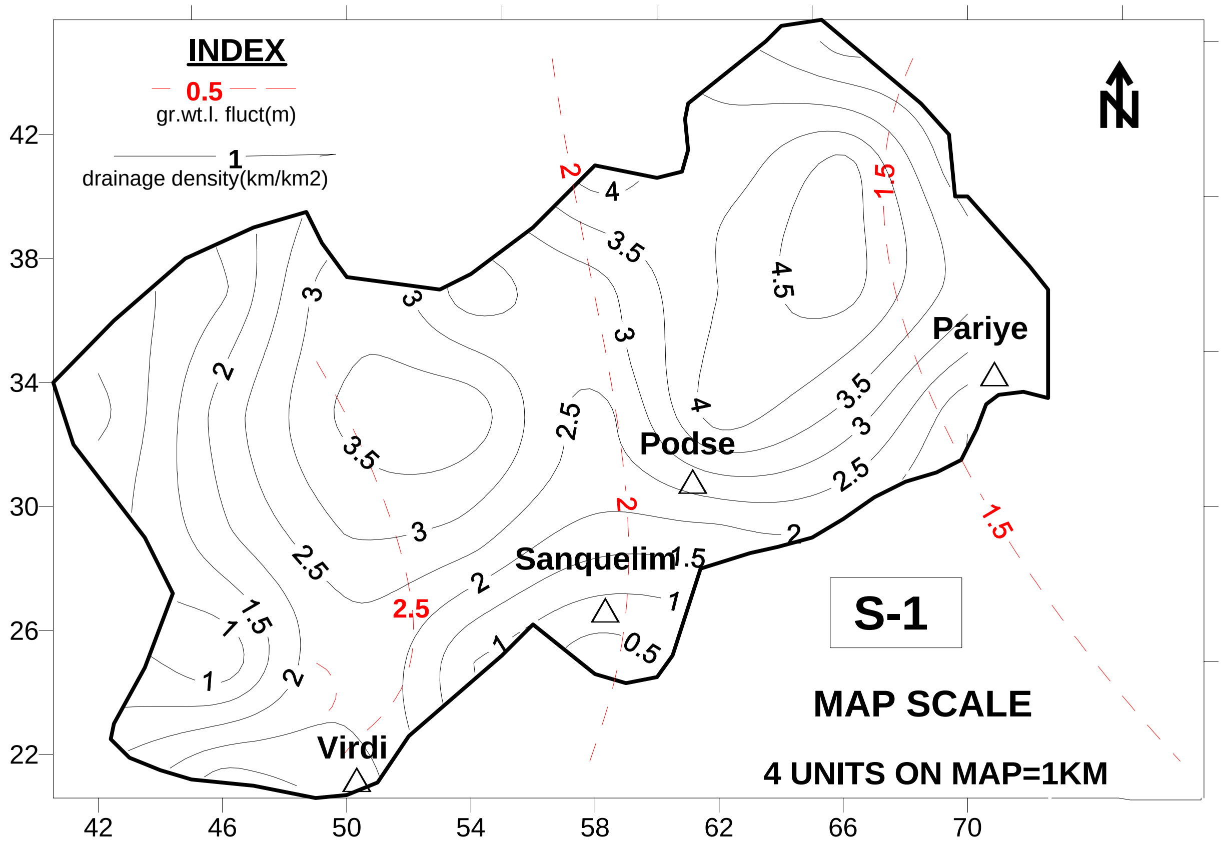


Fig. DD 7: Drainage density and groundwater recharge relation at S-1

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 2674 hacteres
2. Villages: Porium, Podocem, Carapur, Sanquelim, and Maulinguem
3. Land use (in ha): Agriculture (1387), Forest land (513), Builtup/Industrial/hard surfaces (2), Barren/fallow/degraded/waste land (684), Mine pits (40), Water bodies (49).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

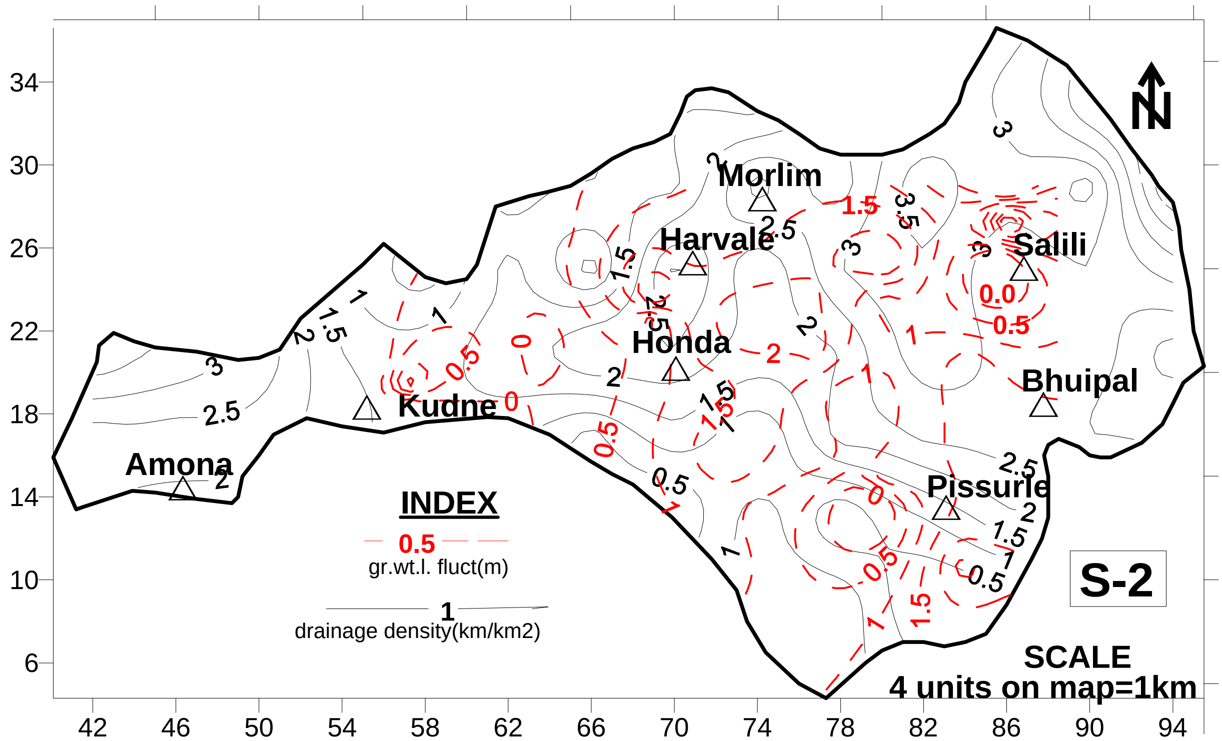


Fig. DD 8: Drainage density and groundwater recharge relation at S-2

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 4518 hacteres
2. Villages: Arvalem, Honda, Cudnem, Pissurlem, Buipal, and Sonshi
3. Land use (in ha): Agriculture (1833), Forest land (355), Builtup/Industrial/hard surfaces (14), Pastures/grass land/open shrubs (239), Barren/fallow/degraded/waste land (1583), Mine pits (180), Wetlands (185), Water bodies (128).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

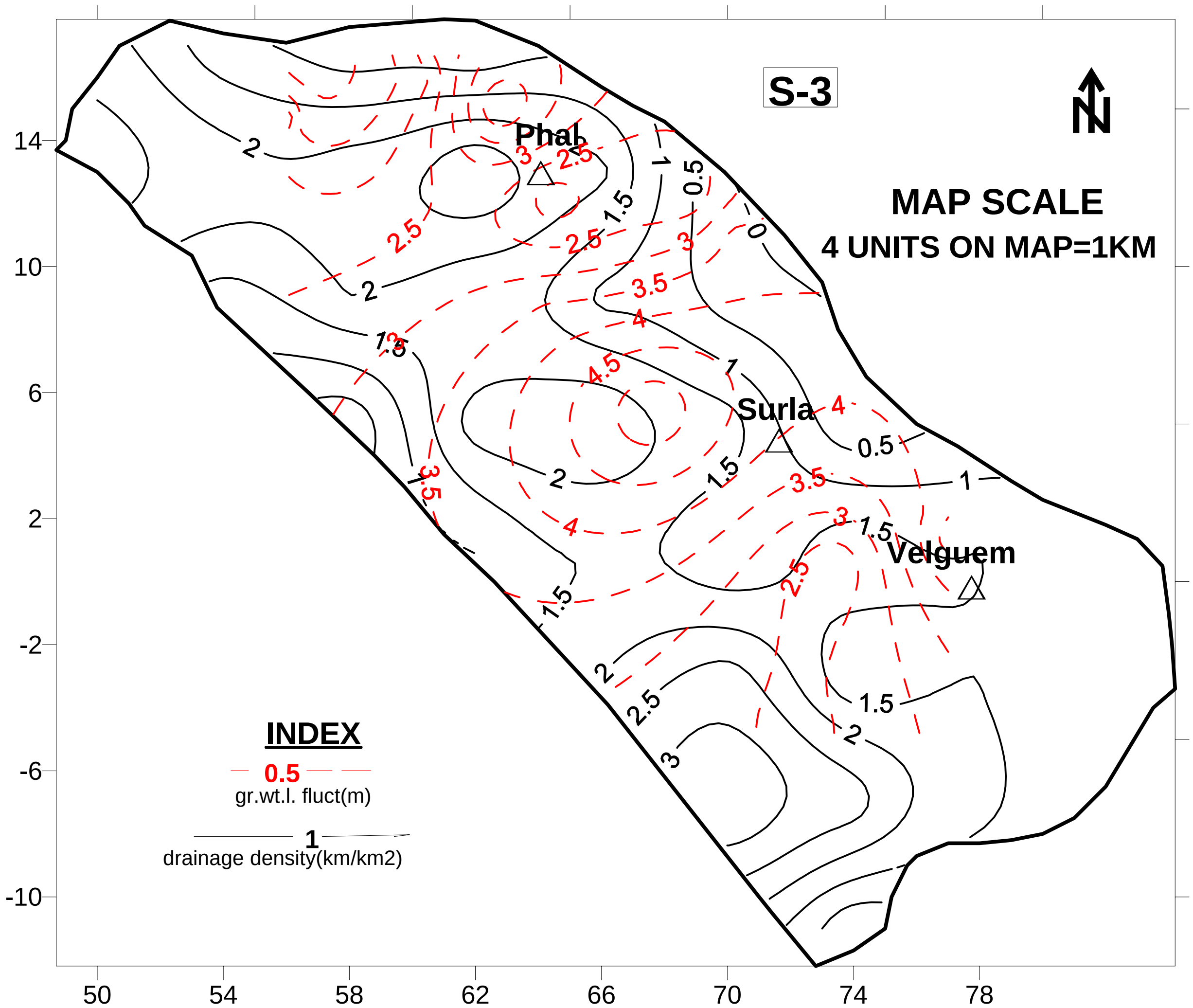


Fig. DD 9: Drainage density and groundwater recharge relation at S-3

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 3035 hacteres
2. Villages: Amone, Navelim, Surla, Sonshi, Cudnem, and Velguem
3. Land use (in ha): Agriculture (978), Pastures/grass land/open shrubs (625), Barren/fallow/degraded/waste land (746), Mine pits (258), Barren dumps (369), Water bodies (59).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

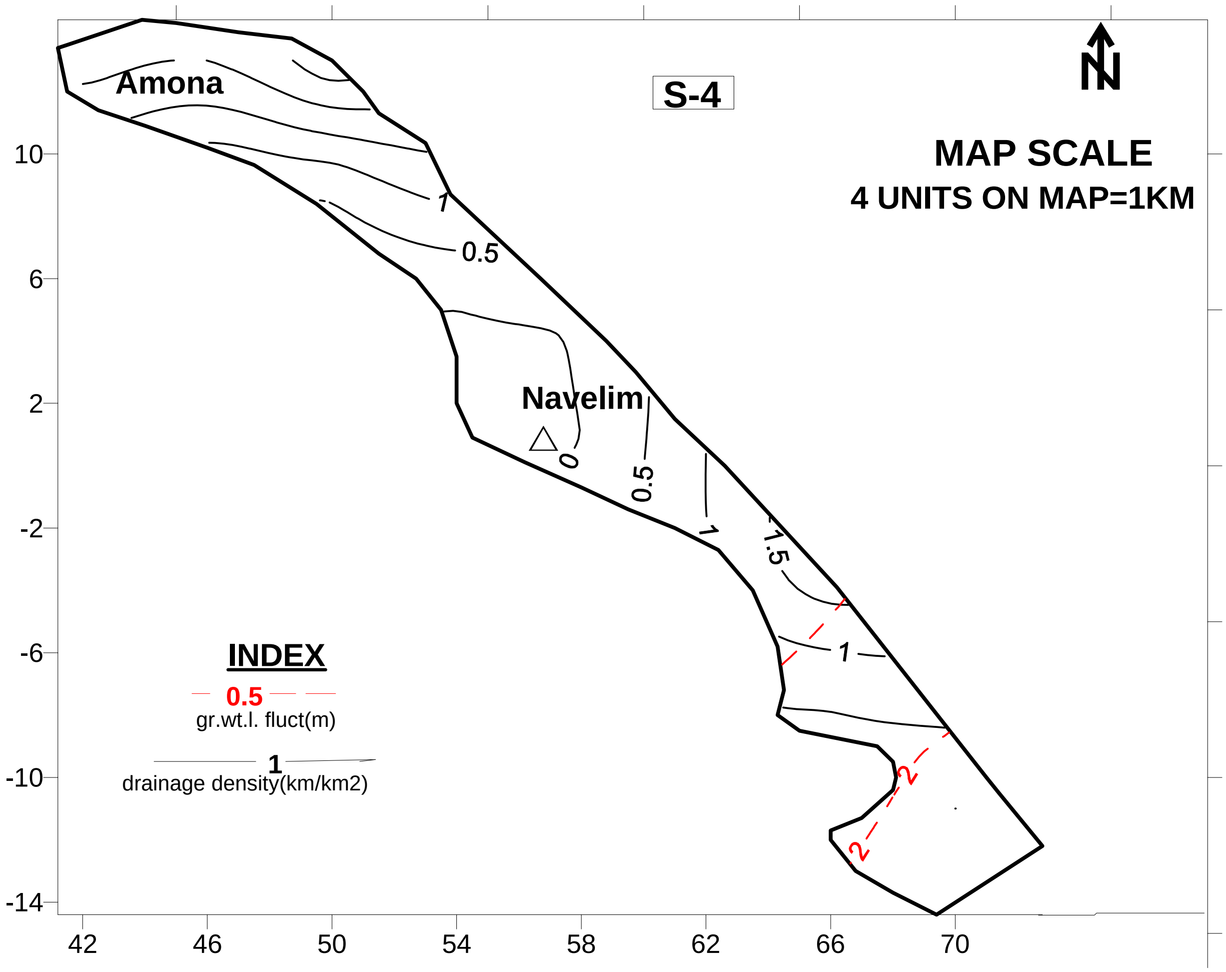


Fig. DD 10: Drainage density and groundwater recharge relation at S-4

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 661 hacteres
2. Villages: Navelim, Amone and Surla
3. Land use (in ha): Agriculture (256), Barren/fallow/degraded/waste land (186), Mine pits (156), Wetlands (63).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Drainage density and groundwater recharge relation: Low drainage density areas correlate with high groundwater recharge indicating permeable formations.

STUDIES OF GROUNDWATER FLOWNET ANALYSIS IN THE TEN-MINING WATERSHED IN NORTH GOA

A flow net is a sketched representation of the flow paths taken by water molecules through the subsurface. The “grid” of a flow-net is comprised of flow-lines (idealized paths followed by water molecules in moving from position of high hydraulic gradient to those of lower head represented by smooth curves at right angles to equipotential lines) and equipotential lines (lines along which the hydraulic head is equal). Flow-net is a very powerful analytical tool for studying the groundwater behavior. Flow-nets may be constructed by a number of procedures including trial-error sketching; physical modeling, electrical analog method, and computer assisted mathematical modeling.

In the present study manual as well as computer assisted flow-net sketching has been adopted. The input to the program includes X and Y co-ordinates of observation wells and water level data above msl in meters (Z co-ordinate). The catchment boundary is plotted using X and Y data manually sampled from the base map along the boundary.

The following contour maps have been constructed for all the ten watersheds:
Groundwater table flow-net for May 2003.
Groundwater table flow-net for June 2003.

Note: Kriging technique is used for plotting of various contours as it was found that it is best-fit method for plotting of smooth contours (Vijay Kumar and Remadevi, 2003).

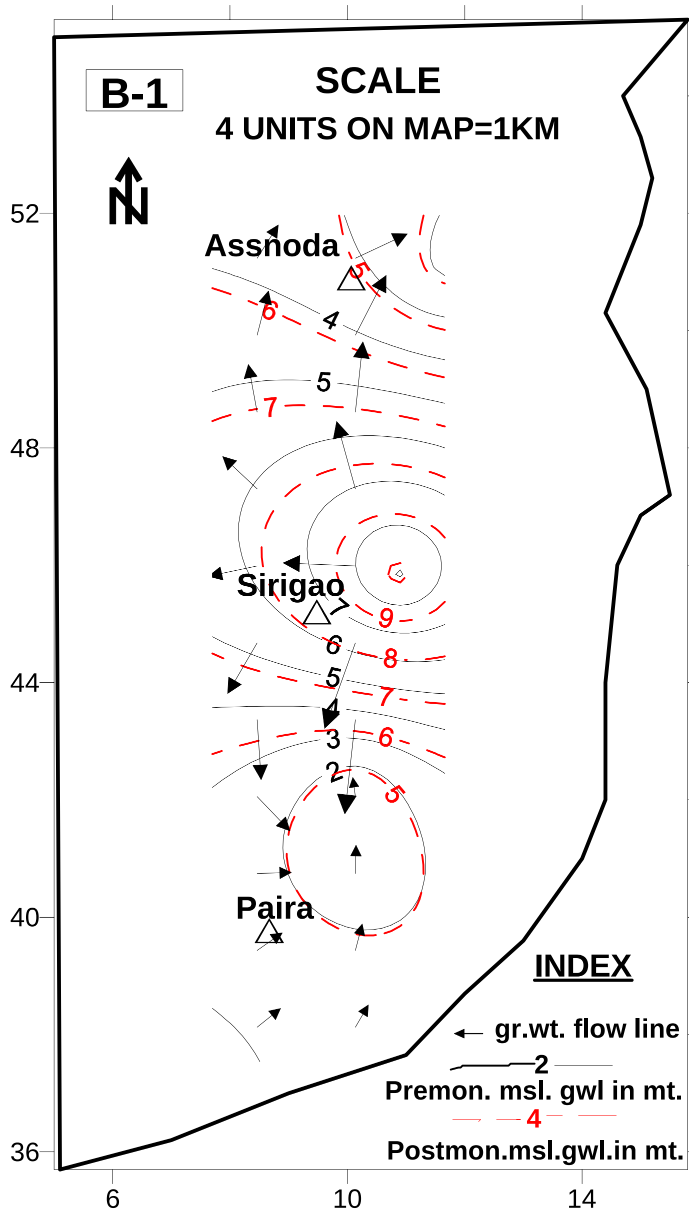


Fig. FN 1: Pre and post-monsoon groundwater flow nets for watershed B-1

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 391 hacteres
2. Villages: Sirigao
3. Land use (in ha): Agriculture (107), Barren/fallow/degraded/waste land (52), Mine pits (52), Barren dumps (89), Vegetated dumps (57), Wetlands (34)
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): -26
7. Percentage and category of groundwater development: 108, Red
8. Average Groundwater fluctuation (m): 2.14
9. Groundwater flow domain: In conformity with topography

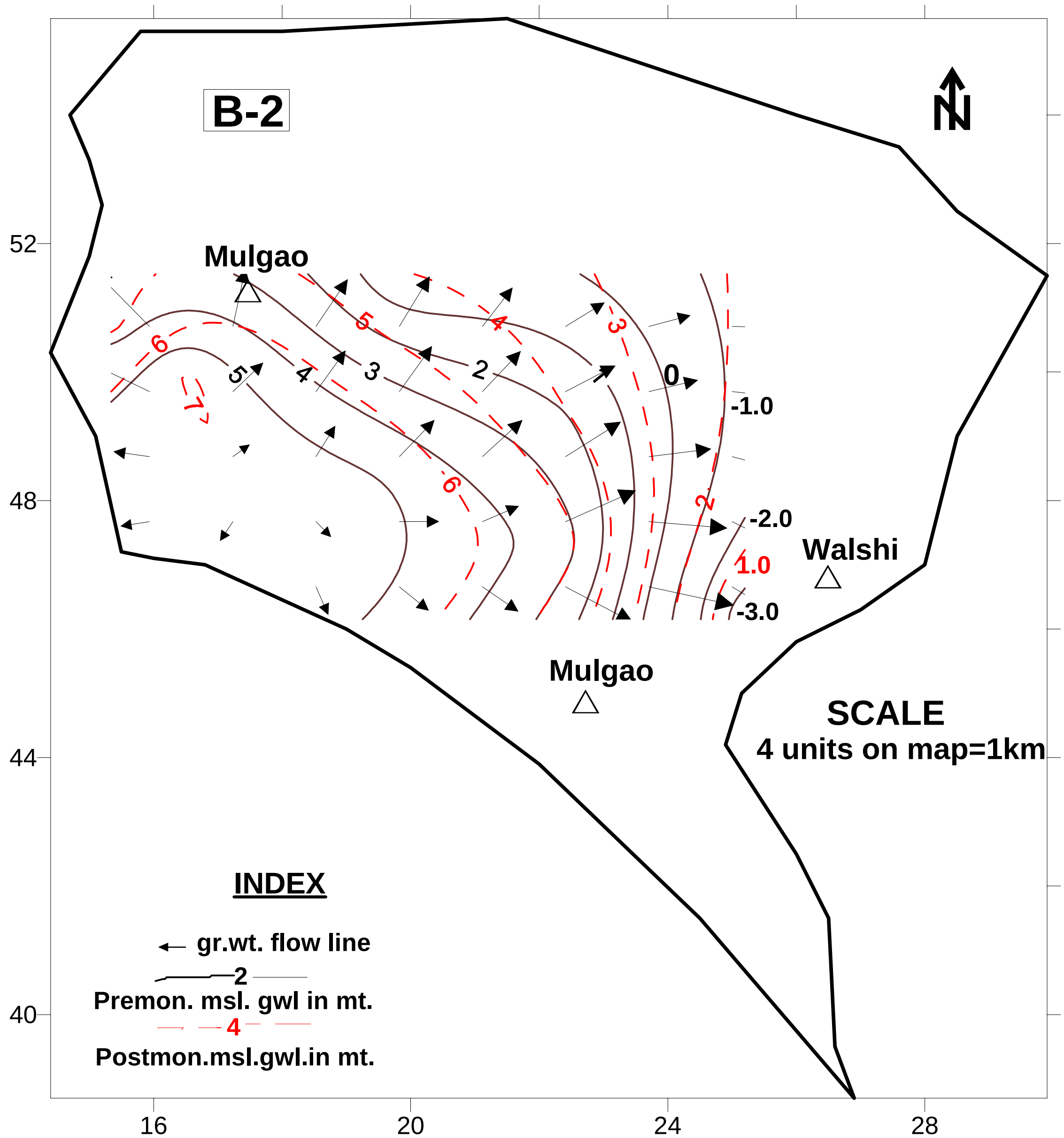


Fig. FN 2: Pre and post-monsoon groundwater flow nets for watershed B-2

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 861 hacteres
2. Villages: Mulgao and Lamgao
3. Land use (in ha): Agriculture (511), Barren/fallow/degraded/waste land (225), Mine pits (68), Vegetated dumps (51), Water bodies (7).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 97
7. Percentage and category of groundwater development: 86, Black
8. Average Groundwater fluctuation (m): 2.23
9. Groundwater flow domain: In conformity with topography

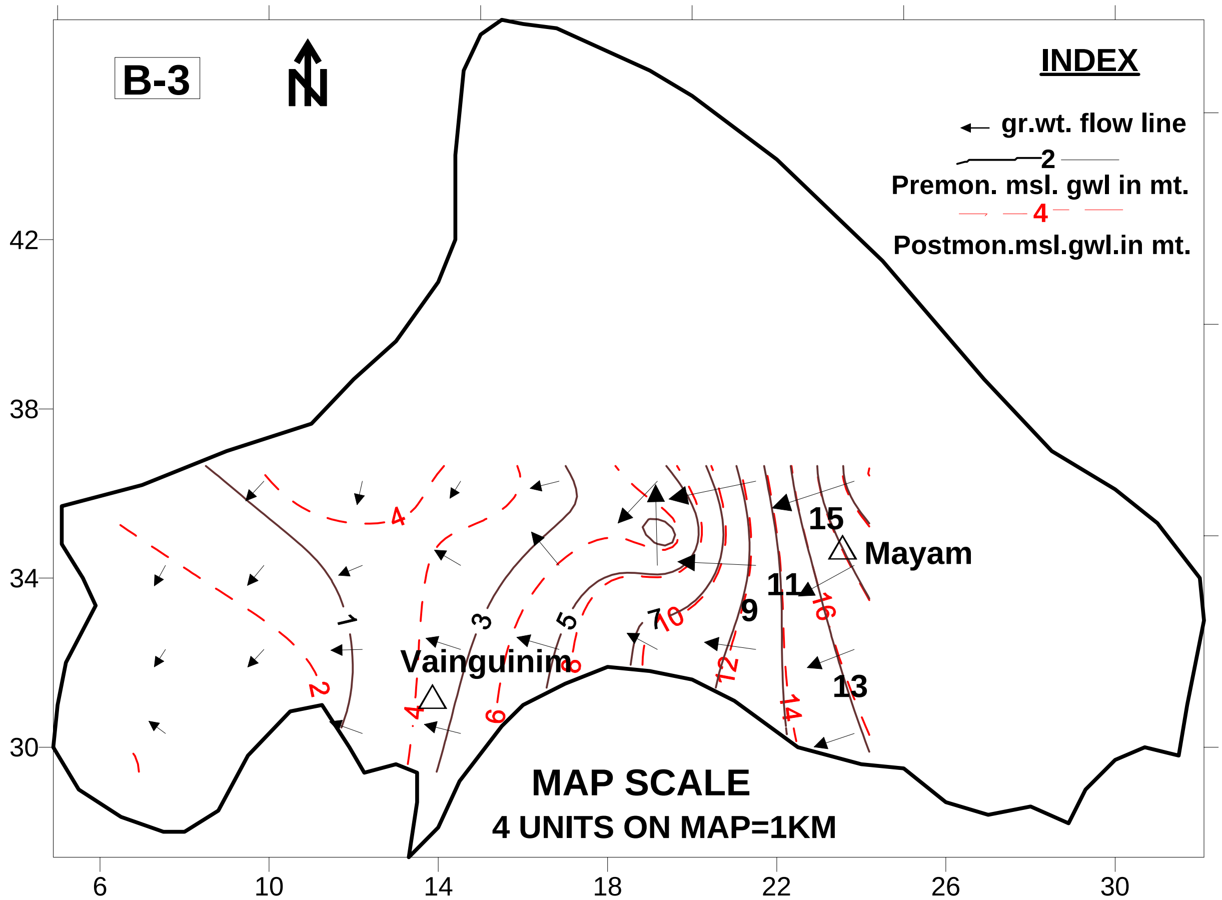


Fig. FN 3: Pre and post-monsoon groundwater flow nets for watershed B-3

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 1920 hacteres
2. Villages: Mayem, Lamgao and Vainguinim
3. Land use (in ha): Agriculture (1082), Builtup/Industrial/hard surfaces (67), Barren/fallow/degraded/waste land (210), Mine pits (134), Barren dumps (76), Vegetated dumps (35), Wetlands (160), Water bodies (157).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 494
7. Percentage and category of groundwater development: 57,Gray
8. Average Groundwater fluctuation (m): 2.47
9. Groundwater flow domain: In conformity with topography

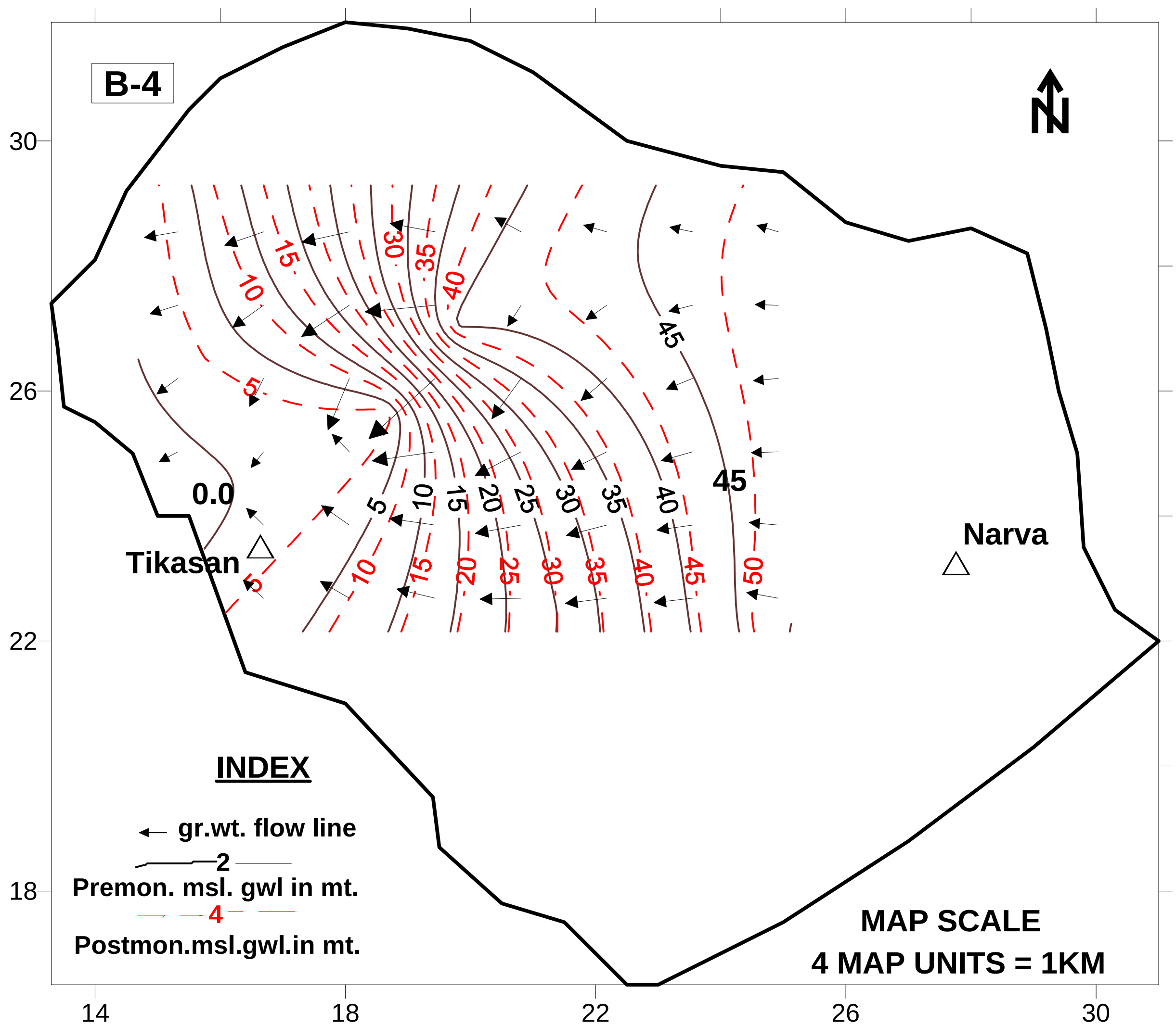


Fig. FN 4: Pre and post-monsoon groundwater flow nets for watershed B-4

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 1172 hacteres
2. Villages: Aturli and Narova
3. Land use (in ha): Agriculture (782), Builtup/Industrial/hard surfaces (53), Barren/fallow/degraded/waste land (150), Water bodies (187).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 199
7. Percentage and category of groundwater development: 69, Gray
8. Average Groundwater fluctuation (m): 3.03
9. Groundwater flow domain: In conformity with topography

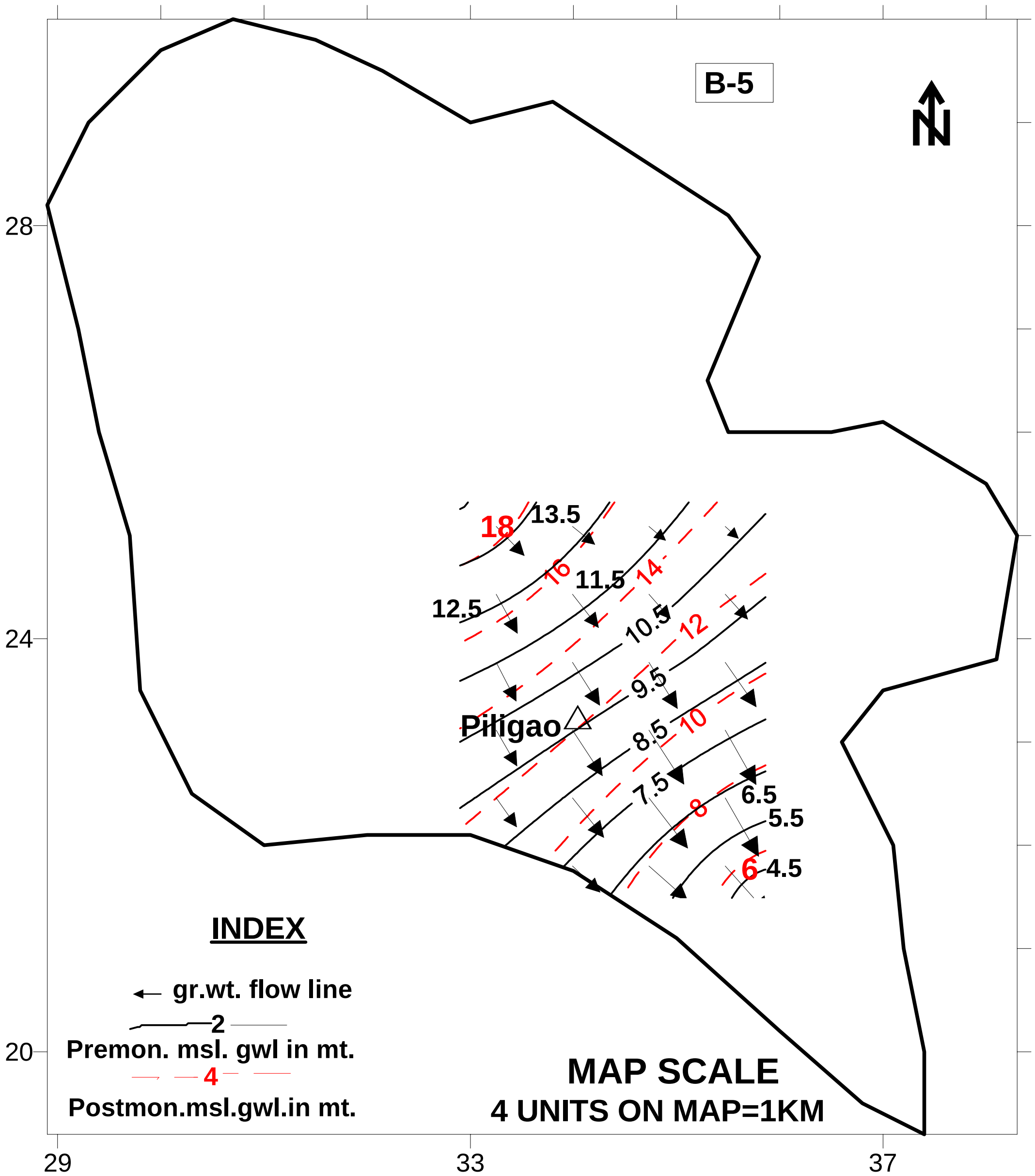
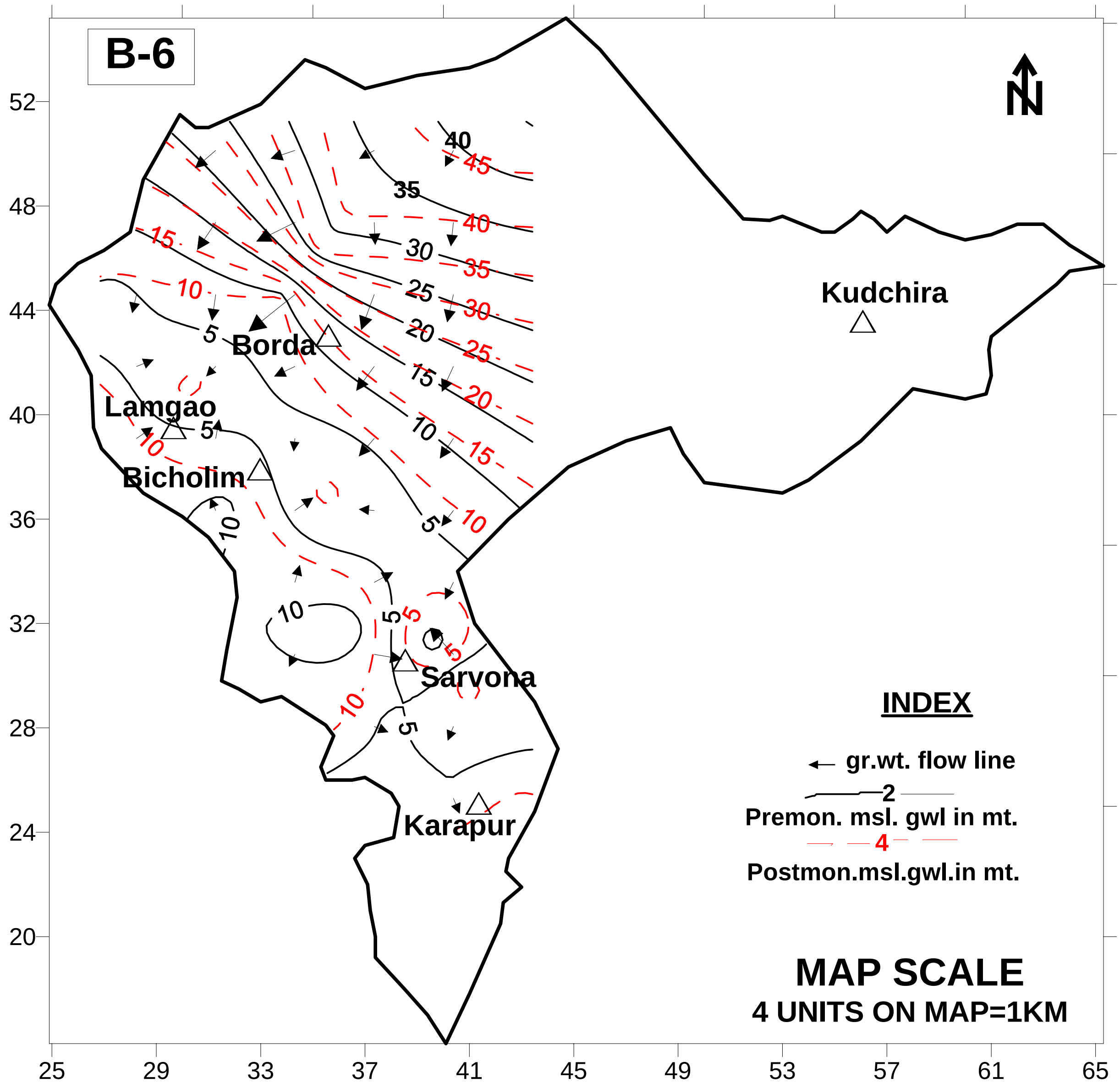


Fig. FN 5: Pre and post-monsoon groundwater flow nets for watershed B-5

1. Basin Area: 400 hacteres
2. Villages: Piligao
3. Land use (in ha): Agriculture (231), Barren/fallow/degraded/waste land (92), Water bodies (76).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): -20
7. Percentage and category of groundwater development: 109, Red
8. Average Groundwater fluctuation (m): 0.95
9. Groundwater flow domain: In conformity with topography



10. **Fig. FN 6: Pre and post-monsoon groundwater flow nets for watershed B-6**

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 3778 hacteres
2. Villages: Lamgao, Ona, Bicholim, Sarvona and Cudchirem
3. Land use (in ha): Agriculture (1997), Builtup/Industrial/hard surfaces (255), Pastures/grass land/open shrubs (960), Barren/fallow/degraded/waste land (412), Mine pits (58), Wetlands (47), Water bodies (49).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 2266
7. Percentage and category of groundwater development: 41, White
8. Average Groundwater fluctuation (m): 3.32
9. Groundwater flow domain: In conformity with topography

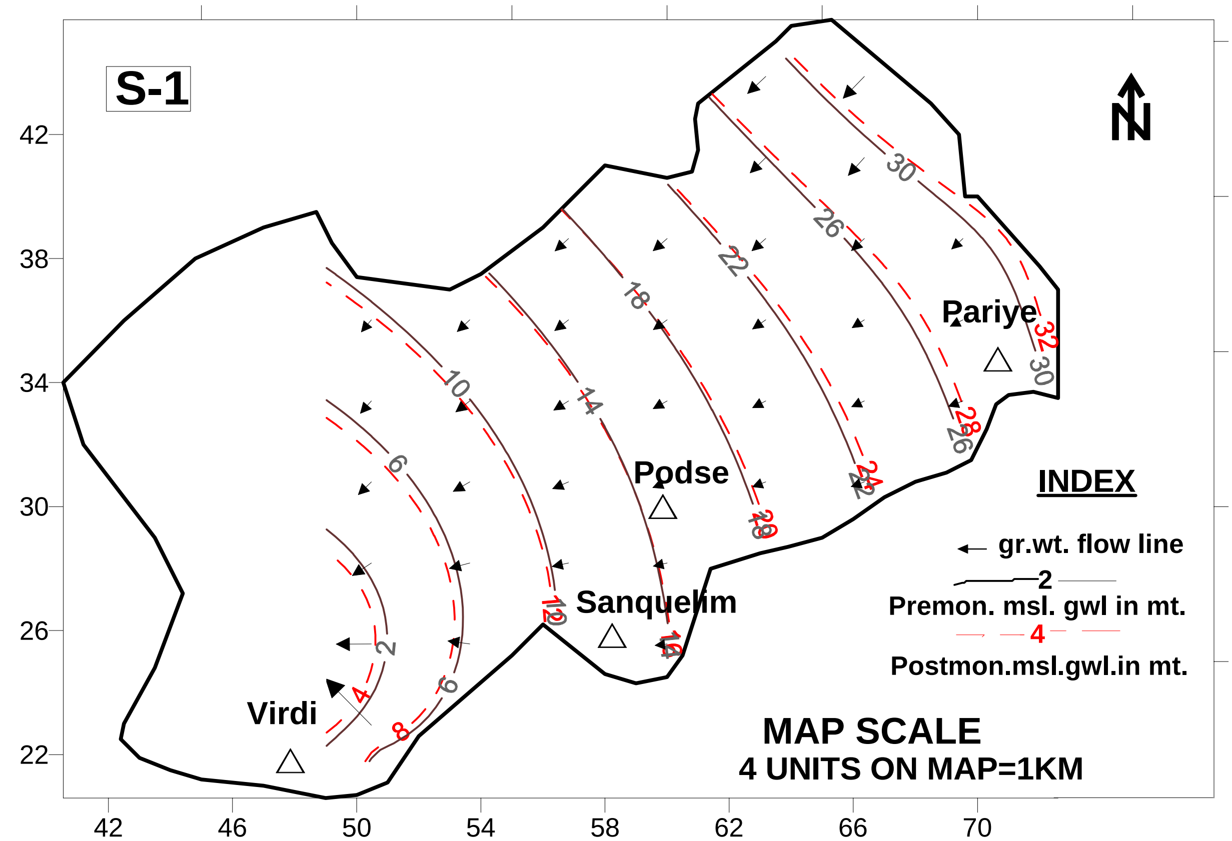


Fig. FN 7: Pre and post-monsoon groundwater flow nets for watershed S-1

1. Basin Area: 2674 hacteres
2. Villages: Porium, Podocem, carapur, Sanquelim, and maulinguem
3. Land use (in ha): Agriculture (1387), Forest land (513), Builtup/Industrial/hard surfaces (2), Barren/fallow/degraded/waste land (684), Mine pits (40), Water bodies (49).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 1216
7. Percentage and category of groundwater development: 54, Gray
8. Average Groundwater fluctuation (m): 2.17
9. Groundwater flow domain: In conformity with topography

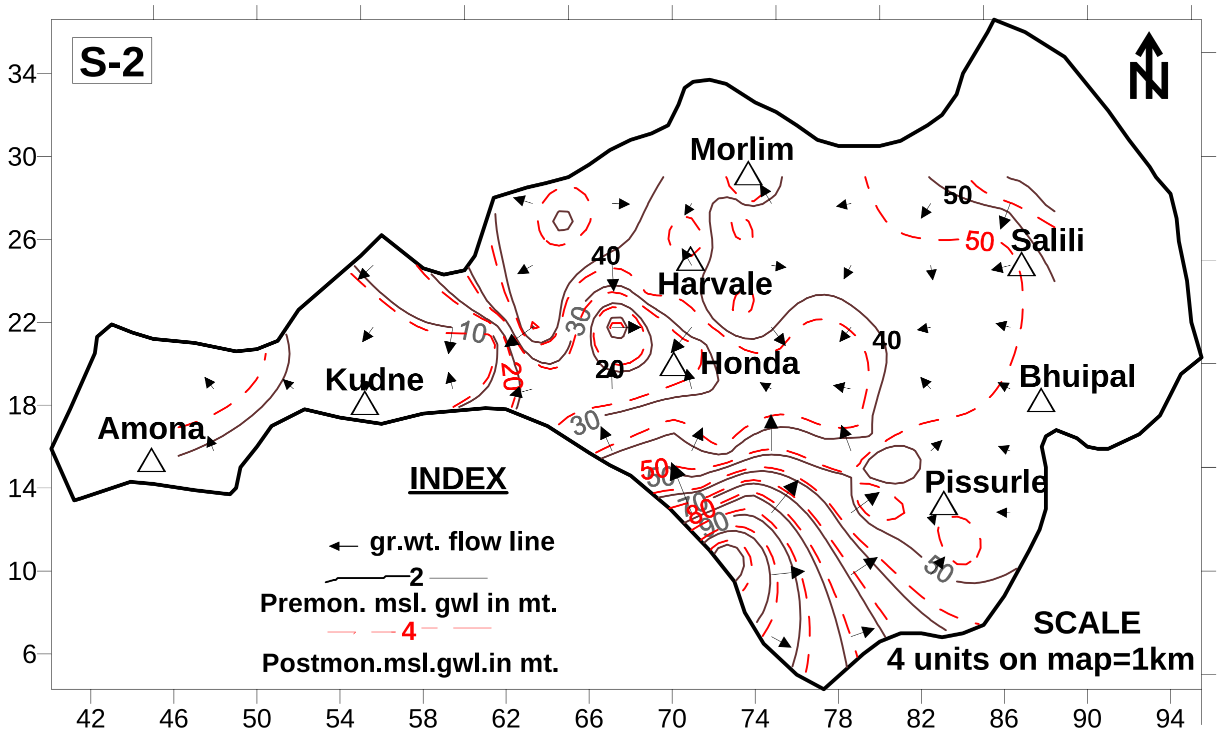


Fig. FN 8: Pre and post-monsoon groundwater flow nets for watershed S-2

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 4518 hacteres
2. Villages: Arvalem, Honda, Cudnem, Pissurlem, Buipal and Sonshi
3. Land use (in ha): Agriculture (1833), Forest land (355), Builtup/Industrial/hard surfaces (14), Pastures/grass land/open shrubs (239), Barren/fallow/degraded/waste land (1583), Mine pits (180), Wetlands (185), Water bodies (128).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 1521
7. Percentage and category of groundwater development: 65, Gray
8. Average Groundwater fluctuation (m): 1.38
9. Groundwater flow domain: In conformity with topography

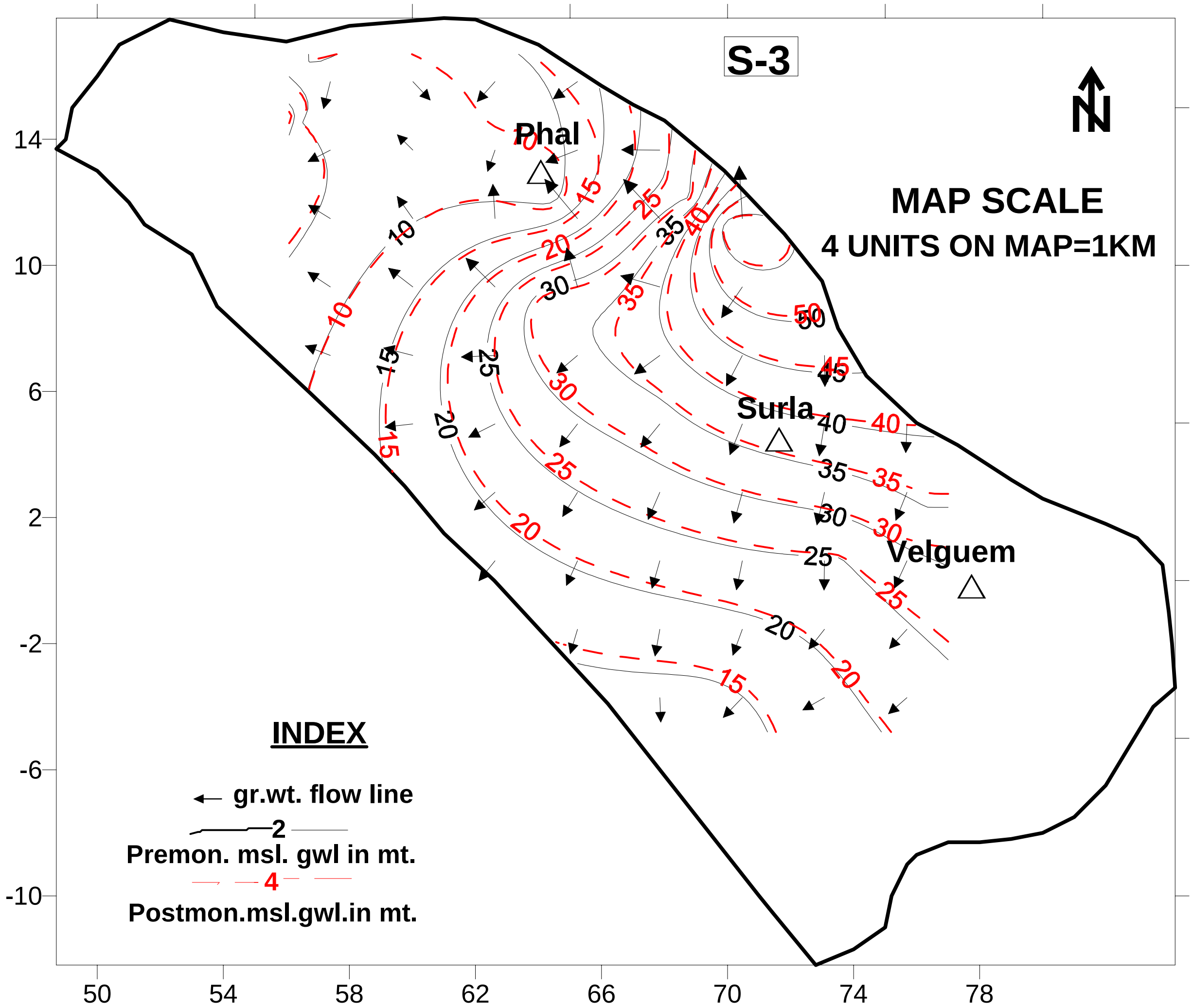


Fig. FN 9: Pre and post-monsoon groundwater flow nets for watershed S-3

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 3035 hacteres
2. Villages: Amone, Navelim, Surla, Sonshi, Cudnem and Velguem
3. Land use (in ha): Agriculture (978), Pastures/grass land/open shrubs (625), Barren/fallow/degraded/waste land (746), Mine pits (258), Barren dumps (369), Water bodies (59).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 1843
7. Percentage and category of groundwater development: 44, White
8. Average Groundwater fluctuation (m): 2.82
9. Groundwater flow domain: In conformity with topography

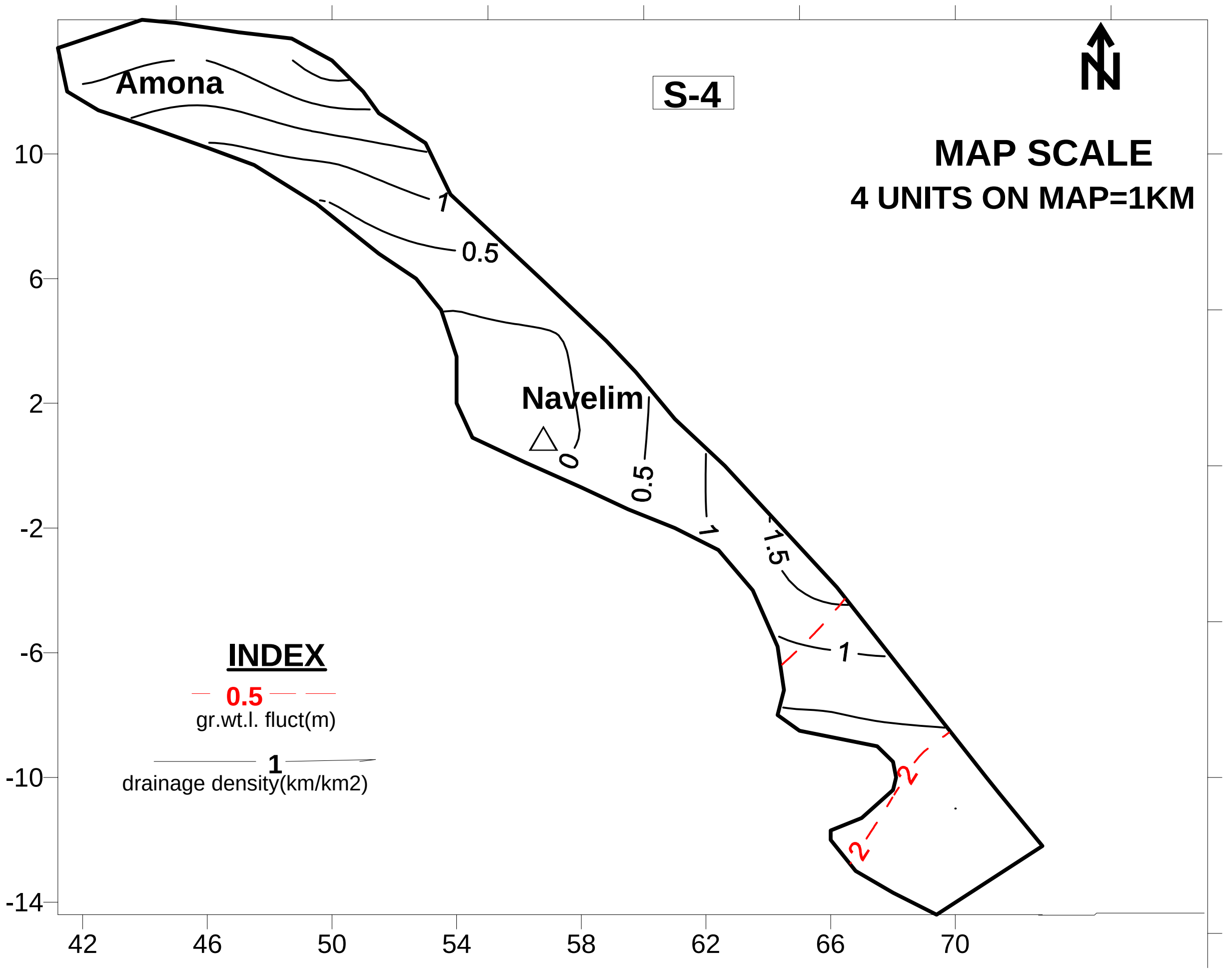


Fig. DD 10: Drainage density and groundwater recharge relation at S-4

HYDROGEOLOGICAL AND MORPHOMETRIC DESCRIPTION OF THE WATERSHED

1. Basin Area: 661 hacteres
2. Villages: Navelim, Amone and Surla
3. Land use (in ha): Agriculture (256), Barren/fallow/degraded/waste land (186), Mine pits (156), Wetlands (63).
4. Geology: Laterite on the surface
5. Aquifer types: Unconfined shallow lateritic aquifer
6. Groundwater Balance (Ham): 153
7. Percentage and category of groundwater development: 72, Gray
8. Average Groundwater fluctuation (m): 1.93
9. Groundwater flow domain: In conformity with topography

Appendix-A

GROUNDWATER BALANCE SHEETS OF ALL 10 MINING WATERSHEDS AND THEIR STATUS OF GROUNDWATER USE

1. **ESTIMATION OF BASINWISE WATER REQUIREMENT IN THE NORTH GOA MINING AREA BASED ON SECTORAL DEMANDS**

2. **ESTIMATION OF BASIN WISE GROUNDWATER RECHARGE BASED ON BALSEQ MODEL RESULTS FOR NORTH GOA MINING AREA**

3. **ESTIMATION OF BASIN WISE GROUNDWATER DRAFT IN THE MINING AREA OF NORTH GOA**

I. ESTIMATION OF BASINWISE WATER REQUIREMENT IN THE NORTH GOA MINING AREA BASED ON SECTORAL DEMANDS

Table-1: Basin wise Domestic Water Requirements

S.no.	WS-No.	Taluka Name	Total WS Area		Pop. in WS 1991*	Population distribution in the WS, 1991		Annual Water Requirement				Total water requirement per year	
			Ha	Km^2		Urban	Rural	* Urban @ 0.0073 Ham		* Rural @ 0.0064 Ham		Ham	Km^3
								Ham	Km^3	Ham	Km^3		
1	B-1	Bicholim	391	3.91	1348	331	1053	2.42	2.42×10^{-5}	2.12	2.12×10^{-5}	4.54	4.54×10^{-5}
2	B-2	Bicholim	861	8.61	3048	729	2320	5.32	5.32×10^{-5}	4.67	4.67×10^{-5}	9.99	9.99×10^{-5}
3	B-3	Bicholim	1920	19.20	6797	1625	5173	11.86	11.86×10^{-5}	10.40	10.40×10^{-5}	22.26	22.26×10^{-5}
4	B-4	Bicholim	1172	11.72	4149	992	3157	7.24	7.24×10^{-5}	6.35	6.35×10^{-5}	13.59	13.59×10^{-5}
5	B-5	Bicholim	400	4.00	1416	338	1078	2.47	2.47×10^{-5}	2.16	2.16×10^{-5}	4.63	4.63×10^{-5}
6	B-6	Bicholim	3778	37.78	13374	3196	10178	23.33	23.33×10^{-5}	20.45	20.45×10^{-5}	43.78	43.78×10^{-5}
7	S-1	Sattari+ Bicholim	2674	26.74	6070	1141	4929	8.33	8.33×10^{-5}	7.30	7.30×10^{-5}	15.63	15.63×10^{-5}
8	S-2	Sattari	4518	45.18	15994	3823	12171	27.91	27.91×10^{-5}	24.47	24.47×10^{-5}	52.38	52.38×10^{-5}
9	S-3	Bicholim	3034	30.34	10740	2567	8173	18.74	18.74×10^{-5}	16.43	16.43×10^{-5}	35.17	35.17×10^{-5}
10	S-4	Bicholim	661	6.61	2340	559	1781	4.08	4.08×10^{-5}	3.58	3.58×10^{-5}	7.66	7.66×10^{-5}

* As per IS: 1172; 1993, urban water requirement of 200 lpcd and rural requirement of 175 lpcd. Population density is 354 and 100 per km^2 respectively for Bicholim and Sattari. The urban and rural population respectively is 23.9 and 76.1 for Bicholim taluka and 13.7 and 86.3 for Sattari taluka.

Note: WS refers to Water Shed; some watersheds do not strictly confine to the taluka boundaries.

Table-2: Irrigation Water Requirement (mainly for Paddy Cultivation)

S.No.	WS No.	Taluka Name	Area under Agriculture		Average annual water requirement for Paddy*	Total water requirement per year	
			Ha	Km^2	(m)	Ham	Km^3
1	B-1	Bicholim	107.31	1.0731	0.55	59.02	59.02×10^{-5}
2	B-2	Bicholim	510.94	5.1094	0.55	281.02	281.02×10^{-5}
3	B-3	Bicholim	1081.97	10.8197	0.55	595.08	595.08×10^{-5}
4	B-4	Bicholim	782.10	7.8210	0.55	430.16	430.16×10^{-5}
5	B-5	Bicholim	231.90	2.3190	0.55	127.55	127.55×10^{-5}
6	B-6	Bicholim	1997.44	19.9744	0.55	1098.59	1098.59×10^{-5}
7	S-1	Sattari+Bicholim	1386.81	13.8681	0.55	762.75	762.75×10^{-5}
8	S-2	Sattari	1833.08	18.3308	0.55	1008.19	1008.19×10^{-5}
9	S-3	Bicholim	978.09	9.7809	0.55	537.95	537.95×10^{-5}
10	S-4	Bicholim	256.08	2.5608	0.55	140.84	140.84×10^{-5}

* CGWB and Department of Agriculture, Govt., of Goa, 1997

Table-3: Industrial Water Requirements

S.No.	WS No.	Taluka Name	Industrial Estate Water Requirement	Annual water requirement	
				Ham	Km^3
1	B-1	Bicholim	-	-	-
2	B-2	Bicholim	-	-	-
3	B-3	Bicholim	-	-	-
4	B-4	Bicholim	-	-	-
5	B-5	Bicholim	-	-	-
6	B-6	Bicholim	Bicholim Ind. Est. 250 m^3/day	9	9 $x10^{-5}$
7	S-1	Sattari+Bicholim	-	-	-
8	S-2	Sattari	Honda & Pisssurlem Ind. Estate 1900 m^3/day	69	69 $x10^{-5}$
9	S-3	Bicholim	-	-	-
10	S-4	Bicholim	-	-	-

Source: Goa Industrial Development Corporation, Govt., of Goa

The proposed five industrial Estates in the study area at Bordem, Dhumacam, Latambarcem, Ladphe and Sal together would require 108 Ham of water. This demand is not considered in the present computation.

Table-4: Livestock Water Requirements

S.No.	.WS no.	Taluka Name	Area		Live stock* population as per 1991 census	Annual water requirement @ 30 lpcd is 0.0011 Ham	
			Ha	Km^2		Ham	Km^3
1	B-1	Bicholim	391	3.91	313	0.3443	0.3443 $x10^{-5}$
2	B-2	Bicholim	861	8.61	689	0.7579	0.7579 $x10^{-5}$
3	B-3	Bicholim	1920	19.20	1536	1.6896	1.6896 $x10^{-5}$
4	B-4	Bicholim	1172	11.72	938	1.0318	1.0318 $x10^{-5}$
5	B-5	Bicholim	400	4.00	320	0.3520	0.3520 $x10^{-5}$
6	B-6	Bicholim	3778	37.78	3022	3.3242	3.3242 $x10^{-5}$
7	S-1	Sattari+Bicholim	2674	26.74	1591	1.7501	1.7501 $x10^{-5}$
8	S-2	Sattari	4518	45.18	3614	3.9754	3.9754 $x10^{-5}$
9	S-3	Bicholim	3034	30.34	2427	2.6697	2.6697 $x10^{-5}$
10	S-4	Bicholim	661	6.61	529	0.5819	0.5819 $x10^{-5}$

Note: According to 1991 census the cattle population is 80 and 39 per km^2 respectively in Bicholim and Sattari talukas

Table-5: Water Requirements for Wet Beneficiation and Ore Washing

S.No.	Ws No	Taluka name	Name of beneficiation plant	Annual ore concentrate produced	Annual water requirement @ 0.00014 Ham/tonne of ore concentrate	
				Tones	Ham	Km^3
1	B-1	Bicholim	-	-	-	-
2	B-2	Bicholim	-	-	-	-
3	B-3	Bicholim	-	-	-	-
4	B-4	Bicholim	-	-	-	-
5	B-5	Bicholim	Dempos- Piligao	900’000	126	126 $x10^{-5}$
6	B-6	Bicholim	Dempos-Bicholim	350’000	49	49 $x10^{-5}$
7	S-1	Sattari + Bicholim	-	-	-	-
8	S-2	Sattari	Sesa Goa-Cudnem	1000’000	140	140 $x10^{-5}$
9	S-3	Bicholim	D.B.Bandodkar-Cotambi Dempos-Surla	320’000	130	130 $x10^{-5}$
10	S-4	Bicholim	Mangali-Navelim Sesa Goa -Amona	250’000	147	147 $x10^{-5}$

Note: The quantity of water used for beneficiation varies from 1.3 to 1.5 m^3/tone of ore concentrate averaging to about 1.4 m^3/tone of ore concentrate (BRGM Report, 1999, p.32). About 50% of this water comes from groundwater via mine pits. 50% of the remaining water is pumped from tidal Mondovi River as seawater is highly flocculating.

Actually 12 to 15 m^3/tone of ore concentrate is the water requirement for wet beneficiation of which 80% is derived from recirculation via tailing ponds. 20% (i.e. 2.7 m^3/tone) is added afresh and 50% of this i.e. 1.35 m^3/tone is derived from groundwater (BRGM Report, 1999, p.33). Therefore in the present computation, groundwater use of @ 0.00014 Ham/tone of ore concentrate is adopted.

Source: TERI, 1997, Area wide Environmental Quality Management (AEQM) plan for the mining belt of Goa. p.304.

Table-6: Groundwater Drafts Through Active Mine Pits

S.No.	WS No.	Taluka name	Ore Production tones per year	Total groundwater draft per year @ 0.0002 Ham / tone of ore	
				Ham	Km^3
1	B-1	Bicholim	1010,000	202	202 $x10^{-5}$
2	B-2	Bicholim	1160,000	232	232 $x10^{-5}$
3	B-3	Bicholim	-	-	-
4	B-4	Bicholim	-	-	-
5	B-5	Bicholim	-	-	-
6	B-6	Bicholim	-	-	-
7	S-1	Sattari + Bicholim	-	-	-
8	S-2	Sattari	3960,000	792	792 $x10^{-5}$
9	S-3	Bicholim	1350,000	270	270 $x10^{-5}$
10	S-4	Bicholim	-	-	-
			Total	**4196**	**4196 $x10^{-5}$**

Source: IBM, 2003, TERI, 1997

II. ESTIMATION OF BASIN WISE GROUNDWATER RECHARGE BASED ON BALSEQ MODEL RESULTS FOR NORTH GOA MINING AREA

Table-7: Area computation under each category of land use based on latest IRS satellite image data

S.No.	Land use class*	Water shed number and area in hectares									
		B-1	**B-2**	**B-3**	**B-4**	**B-5**	**B-6**	**S-1**	**S-2**	**S-3**	**S-4**
1	Agricultural land	107.31	510.94	1081.97	782.10	231.39	1997.44	1386.81	1833.08	978.09	256.08
2	Forest land	-	-	-	-	-	-	512.54	354.66	-	-
3	Builtup/Industrial/hard surfaces etc	-	-	67.26	53.07	-	255.14	2.46	14.08	-	-
4	Pastures/grass land /open shrubs	-	-	-	-	-	959.87	-	238.90	624.82	-
5	Barren/fallow/degraded /waste land etc.	51.80	224.93	209.86	150.21	92.45	411.98	684.24	1583.19	745.98	186.38
6	Mine pits	51.80	67.93	133.53	-	-	57.77	39.76	180.03	257.63	156.18
7	Barren dumps	89.41	-	75.77	-	-	-	-	-	369.35	-
8	Vegetated dumps	56.66	51.03	34.85	-	-	-	-	-	-	-
9	Wetlands	33.63	-	159.77	-	-	47.11	-	185.39	-	62.52
10	Water bodies including mine pits having water	-	6.63	157.23	187.05	75.88	48.60	48.60	128.18	58.76	-
	Total Area (hectares)	390.61	861.46	1920.24	1172.4	399.72	3777.91	2674.41	4517.51	3034.6	661.16

*Land use classification and area are derived from the latest IRS satellite data of the study area

Table-8: Computation of groundwater recharge for each of the land use class using watershed area and BALSEQ derived recharge rates for different land use classes

S.No.	Land use Class	BALSEQ recharge (m)	Water shed number and groundwater recharge in Ham									
			B-1	B-2	B-3	B-4	B-5	B-6	S-1	S-2	S-3	S-4
1	Agricultural land	0.54	57.95	275.91	584.26	422.33	124.95	1078.62	748.88	989.86	528.17	138.28
2	Forest land	1.97	-	-	-	-	-	-	1009.70	698.68	-	-
3	Builtup/Industrial/hard surfaces etc	0.69	-	-	46.41	36.62	-	176.05	1.70	9.72	-	-
4	Pastures/grass land /open shrubs	2.08	-	-	-	-	-	1996.53	-	496.91	1299.63	-
5	Barren/fallow/degraded /waste land etc.	1.19	61.64	267.67	249.73	178.75	110.02	490.26	814.25	1884.00	887.72	221.79
6	Mine pits	1.19	61.64	80.84	158.90	-	-	68.75	47.31	214.24	306.58	185.85
7	Barren dumps	0.73	65.27	-	55.31	-	-	-	-		269.63	-
8	Vegetated dumps	1.46	82.72	74.50	50.88	-	-	-	-		-	-
9	Wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Water bodies including mine pits having water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Groundwater Recharge	**Ham**	**-**	329.22	698.92	1145.49	637.70	234.97	3810.21	2621.84	4293.41	3291.73	545.92
	Km^3	**$X10^{-5}$**	329.22	698.92	1145.49	637.70	234.97	3810.21	2621.84	4293.41	3291.73	545.92

III. ESTIMATION OF BASIN WISE GROUNDWATER DRAFT IN THE MINING AREA OF NORTH GOA

NORMS ADOPTED IN THE PRESENT STUDY: Based on the filed knowledge and information the following norms have been adopted for estimation of the groundwater drafts:

1. **Domestic water requirement:** 80% of the total water demand [20% is assumed to come from other than groundwater sources]
2. **Irrigation drafts:** 60% of the total irrigation water requirements [balance 40% of the water requirement is assumed to be met from other than groundwater sources]
3. **Industrial drafts:** 50% of the total water requirements [balance 50% is drawn from other sources]
4. **Livestock drafts:** 50% of the requirements [remaining 50% is used from other than groundwater source]
5. **Wet beneficiation of ores:** 10% of the water added afresh [the details are seen in the Table-5]
6. **Real Evapotranspiration losses from groundwater:** Real evapotranspiration derived from BALSEQ model for Paddy fields, Forestlands and vegetated dumps.
7. **Base flow to rivers, streams and spring flow drafts:** 20% of the groundwater recharge for all land covers
8. **Groundwater drafts through active mine pits:** Actual estimated values.

Table-9: ANNUAL GROUNDWATER BALANCE OF DIFFERENT WATERSHEDS NORTH GOA

S. no.	Groundwater User Catogery	Norms Adopted for GW Withdrawal	Groundwater Drafts (Ham) in different watersheds									
			B-1	B-2	B-3	B-4	B-5	B-6	S-1	S-2	S-3	S-4
1	Domestic water drafts	80% of total demands (Table-1)	3.63	7.99	17.81	10.87	3.70	35.02	12.50	41.90	28.14	6.13
2	Irrigation water drafts	60% of total requirement (Table-2)	35.41	168.61	357.05	258.10	76.59	659.15	457.65	604.91	322.77	84.50
3	Industrial water drafts	50% of total requirement (Table-3)	-	-	-	-	-	4.5	-	34.5	-	-
4	Live stock water drafts	50% of total requirement (Table-4)	0.172	0.379	0.845	0.516	0.176	1.662	0.875	1.988	1.335	0.291
5	Water drafts for wet beneficiation of ores	10% of water added afresh (Table-5)	-	-	-	-	126	49	-	140	130	147
6	Real Evapotranspira-tion losses from groundwater	Paddy field area x 0.382 mts	12.34	21.2	24.70	41.94	1.69	32.53	40.93	43.12	38.16	46.07
		Dense forest cover area x 0.721 mts	-	-	-	-	-	-	369.54	255.71	-	-
		Vegetated mine dump areax0.629 mts	35.64	32.10	21.92	-	-	-	-	-	-	-
7	GW contribution to base flow and spring flows	20% of aquifer recharge derived from BALSEQ model (Table-8)	65.84	139.78	229.10	127.54	46.99	762.04	524.37	858.68	658.35	109.18
8	GW drafts through active mine pits working below WT	Actual computed @ of 2 m^3 / tone of ore mined out (Table-6)	202	232	-	-	-	-	-	792	270	-
9	Total Groundwater Draft in the Watershed (Ham)		355.03	602.06	651.43	438.97	255.09	1543.90	1405.87	2772.81	1448.76	393.17
10	Total groundwater Recharge from BALSEQ model (Ham)		329.22	698.92	1145.49	637.70	234.97	3810.21	2621.84	4293.41	3291.73	545.92
11	Groundwater Balance (Ham)		-25.81	96.81	494.06	198.75	-20.19	2266.31	1215.97	1520.60	1842.97	152.75
12	% Groundwater Utilization in the watershed as on date		107.84	86.14	56.87	68.84	108.56	40.52	53.62	65.00	44.00	72.02
13	Categorization of the Watershed as per CGWB (1984)		Red	Black	Gray	Gray	Red	White	Gray	Gray	White	Gray

Modified groundwater basin classification criteria:

(1) **White** (Non-Critical)- <50%; (2) **Gray** (Sub-Critical)-50-75%; (3) **Black** (Critical)-75-100%; (4) **Red** (Most-Critical)- >100% of recharged groundwater is being used presently.

Table: 1: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B-1	391	50	0.01	0.02	-0.02	-0.15	-0.31	1.84	-0.36	-0.57	0.68	-1.10	-0.06	0.02
		52	-0.22	-0.04	0.02	0.05	0.03	1.94	-0.21	-0.41	-0.63	-0.23	-0.18	-0.12
		53	-0.10	-0.06	0.02	-1.05	0.52	1.10	0.00	-0.26	-0.27	-0.36	0.06	0.40
		70	-0.76	0.43	-0.09	0.08	-0.21	3.33	-0.53	-0.64	-0.57	0.15	-0.91	-0.28
		71	-0.22	-0.30	-0.08	-0.04	-0.07	2.49	-0.51	-0.34	-0.17	-0.21	-0.26	-0.29
1. Av. W.T. Fluctuation (m)			-0.258	0.01	-0.03	-0.222	-0.008	2.14	-0.322	-0.444	-0.192	-0.35	-0.27	-0.054
2. Groundwater Outflow (Ham)			-4.44	0.17	-0.52	-3.82	-0.14	36.82	-5.54	-7.64	-3.30	-6.02	-4.65	-0.93
3. Groundwater Balance (Ham)			4.40	4.57	4.05	0.23	0.09	36.82	31.28	23.74	20.44	14.42	9.77	8.84
4. % Groundwater Balance			11.95	12.41	10.99	0.60	0.20	100.00	84.95	64.48	55.51	39.16	26.53	24.01
5. Cumulative Outflows (Ham)			-32.42	-32.25	-32.77	-36.59	-36.73	0.00	-5.54	-13.08	-16.38	-22.40	-27.05	-27.98

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 2: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B-2	861	51	-0.17	0.14	-0.03	-0.57	-0.12	1.33	-0.13	-0.25	-0.16	-0.04	0.06	-0.06
		54	-0.08	-0.12	0.07	-0.11	-0.10	1.24	-0.03	-0.05	-0.33	-0.69	0.07	0.13
		55	0.36	0.01	-0.30	0.23	0.00	1.48	-0.96	-0.43	-0.25	0.01	-0.73	0.58
		56	-0.21	0.02	-0.15	-0.40	-0.16	1.84	-0.40	-0.16	-0.27	0.02	-0.16	0.03
		57	-0.28	-0.08	-0.10	-0.46	-0.05	2.04	-0.59	-0.28	-0.05	-0.02	-0.03	-0.10
		58	-0.18	-0.20	-0.12	-0.27	-0.18	3.95	-0.02	-0.89	-1.07	-0.44	-0.41	-0.17
		62	0.05	0.53	-0.79	-0.78	-0.13	3.75	-0.86	-0.26	-0.35	0.07	-0.29	-0.94
1. Av. W.T. Fluctuation (m)			-0.073	0.043	-0.203	-0.337	-0.106	2.233	-0.427	-0.331	-0.354	-0.156	-0.213	-0.076
2. Groundwater Outflow (Ham)			-2.766	1.63	-7.69	-12.77	-4.02	84.59	-16.18	-12.54	-13.41	-5.91	-8.07	-2.88
3. Groundwater Balance (Ham)			22.83	24.46	16.77	4.00	-0.02	0.00	68.41	55.87	42.46	36.55	28.48	25.60
4. % Groundwater Balance			26.99	28.92	19.83	4.73	0.00	100	80.87	66.05	50.20	43.21	33.67	30.26
5. Cumulative Outflows (Ham)			-61.76	-60.13	-67.82	-80.59	84.61	0.00	-16.18	-28.72	-42.13	-48.04	56.11	-58.99

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 3: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B-3	1920	67	-0.06	0.04	-0.23	-0.19	-0.29	3.16	-0.11	-0.96	-0.86	0.06	-0.33	-0.23
		68	0.01	-0.27	-0.23	-0.38	-0.24	2.62	-0.32	-0.48	-0.31	0.08	-0.26	-0.22
		69	-0.05	-0.08	0.00	-0.06	-0.27	1.55	-0.36	-0.30	-0.15	-1.53	1.50	-0.25
		72	-0.13	-0.54	-0.23	-0.62	0.01	3.16	-0.60	-0.37	-0.21	0.05	-0.17	-0.35
		73	-0.05	0.00	-0.08	-0.17	-0.16	2.94	-0.63	-0.93	-0.54	0.15	-0.22	-0.31
		74	-0.15	0.09	0.08	-0.08	-0.14	1.37	-0.48	-0.23	-0.23	0.08	-0.12	-0.19
		75	-0.10	0.01	0.04	5.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1. Av. W.T. Fluctuation (m)			-0.076	-0.107	-0.093	0.610	-0.182	2.467	-0.417	-0.545	-0.383	-0.185	0.067	-0.258
2. Groundwater Outflow (Ham)			-6.42	-9.04	-7.86	51.53	-15.38	208.41	-35.23	-46.04	-32.36	-15.63	5.66	-21.80
3. Groundwater Balance (Ham)			56.59	47.55	39.69	91.22	75.84	208.41	173.18	127.14	94.78	79.15	84.81	63.01
4. % Groundwater Balance			27.15	22.82	19.04	43.77	36.39	100	83.10	61.00	45.48	37.98	40.69	30.23
5. Cumulative Outflows (Ham)			-151.82	-160.86	-168.72	-117.19	-132.57	0.00	-35.25	-81.27	-113.63	-129.26	-123.6	-145.4

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 4: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B-4	1172	76	0.04	-0.13	-0.12	-1.01	0.08	2.18	-0.25	-0.42	-0.15	-0.03	-0.11	-0.14
		77	-0.02	-0.05	-0.32	0.15	-0.07	1.98	-0.02	-0.76	-0.48	-0.06	-0.30	-0.17
		78	-0.04	-0.15	-0.38	0.41	-0.36	3.21	0.10	-1.32	-0.75	-0.06	-0.38	-0.40
		79	-0.03	-0.13	0.02	-0.18	-0.51	2.58	-0.06	-0.79	-0.57	-0.03	-0.09	-0.27
		80	-0.10	-0.11	-0.07	-0.39	-0.05	4.98	-0.84	-1.85	-0.92	-0.03	-0.18	-0.50
		81	-0.04	-0.08	-0.06	-0.10	0.08	3.26	-0.47	-0.49	-1.11	-0.08	-0.71	-0.36
1. Av. W.T. Fluctuation (m)			-0.032	-0.108	-0.970	-0.187	-0.138	3.032	-0.257	-0.938	-0.663	-0.048	-0.295	-0.307
2. Groundwater Outflow (Ham)			-1.65	-5.57	-50.02	-9.64	-7.12	156.35	-13.25	-48.37	-34.19	-2.48	-15.21	-15.83
3. Groundwater Balance (Ham)			25.37	19.80	-30.22	-39.91	-47.03	156.35	143.1	94.73	60.54	58.06	42.85	27.02
4. % Groundwater Balance			16.23	12.66	-19.33	-25.53	-30.08	100	91.53	60.59	38.72	37.13	27.41	17.28
5. Cumulative Outflows (Ham)			-130.98	-136.55	-186.57	-196.21	-203.33	0.00	-13.25	-61.62	-95.81	-98.29	-113.5	-129.33

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 5: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B-5	400	82	-	-	-	-	-	-	-	-	-	-	-	-
		98	-0.20	0.12	-0.06	-0.23	0.95	0.95	-0.78	-0.15	-0.42	-0.04	-0.29	-0.07
1. Av. W.T. Fluctuation (m)			-0.200	-0.120	-0.060	-0.230	0.95	0.95	-0.780	-0.150	-0.420	-0.040	-0.290	-0.070
2. Groundwater Outflow (Ham)			-3.52	-2.112	-1.056	-4.048	16.72	16.72	-13.73	-2.64	-7.39	-.704	-5.104	-1.23
3. Groundwater Balance (Ham)			-17.60	-19.71	-20.77	-24.81	16.72	16.72	2.99	0.35	-7.04	7.744	-12.848	-14.078
4. % Groundwater Balance			-105.3	-117.9	-124.2	-148.39	100.00	100.00	17.88	02.09	-42.11	-46.32	-76.85	-84.20
5. Cumulative Outflows (Ham)			-34.32	-36.43	-37.49	-41.54	0.00	0.00	-13.73	-16.37	-23.76	-24.46	-29.57	30.80

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 6: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B-6	3778	59	-0.10	-0.17	-0.08	-0.10	0.02	2.09	-0.24	-0.30	-0.37	-0.22	-0.23	-0.30
		60	-0.19	-0.16	-0.13	-0.17	-0.08	2.12	-0.08	0.47	-0.85	-0.46	-0.29	-0.18
		61	-0.08	-0.05	-0.07	-0.09	-0.04	4.42	-0.32	-1.74	-1.08	-0.50	-0.28	-0.17
		63	-0.12	-0.19	-0.10	-1.53	0.15	5.06	0.12	-1.61	-0.60	0.07	-0.47	-0.78
		64	-0.16	-0.75	0.01	0.24	-0.01	0.54	5.04	-2.10	-1.73	0.02	-1.00	-0.10
		65	-0.93	-0.07	-0.39	-4.68	2.96	9.39	1.60	-3.36	-2.67	-0.96	-0.73	-0.16
		66	-0.56	-0.50	-0.19	-0.24	-0.11	3.82	-0.06	-0.32	-0.19	0.10	-1.14	-0.61
		83	-0.07	-0.51	-0.27	-0.20	0.11	1.92	-0.01	-0.10	-0.12	0.45	-0.11	-1.09
		84	-0.15	0.02	0.09	0.72	-1.17	2.56	-0.49	-0.56	-0.33	0.04	-0.43	-0.30
		85	-0.16	0.70	-0.05	0.02	-0.08	4.39	0.66	-1.00	-1.97	-1.41	-0.34	-0.76
		86	-0.04	-0.06	0.08	-0.12	0.01	1.79	0.09	-0.93	-0.60	-0.13	-0.05	-0.04
		87	-0.21	-0.46	1.03	-0.86	0.11	2.28	-0.05	-0.71	-0.30	-0.45	-0.13	-0.25
		88	-0.14	0.28	-0.08	0.01	-0.24	2.62	-0.64	-0.63	-0.79	0.24	-0.15	-0.48
		95	-0.28	-0.45	0.10	-0.20	0.06	3.65	0.08	-1.53	-0.44	0.04	-0.64	-0.39
		96	-0.22	0.12	0.18	-0.28	-0.18	2.01	-0.70	-0.44	-0.29	0.14	-0.24	-0.10
		97	-0.24	-0.89	-0.61	-1.37	-1.13	4.45	-0.01	0.00	-0.03	0.03	-0.10	-0.10
1. Av. W.T. Fluctuation (m)			-0.228	-0.196	-0.030	-0.553	0.024	3.319	0.312	-0.929	-0.773	-0.188	-0.396	-0.363
2. Groundwater Outflow (Ham)			-37.90	-32.58	-4.99	-91.93	3.99	551.72	51.86	-154.43	-128.50	-31.25	-65.83	-60.34
3. Groundwater Balance (Ham)			125.33	92.75	87.76	-4.17	-0.18	551.72	603.58	449.15	320.65	289.4	223.57	163.23
4. % Groundwater Balance			20.76	15.37	14.54	0.69	0.00	91.41	100	74.41	50.13	47.95	37.04	27.04
5. Cumulative Outflows (Ham)			-478.25	-510.85	-515.82	-607.75	0.00	0.00	0.00	-154.43	-282.93	-314.18	-380.01	-440.35

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 7: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S-1	2674	89	-0.12	0.03	-0.10	-0.70	-0.03	2.79	-0.38	-0.68	-0.52	-0.23	0.06	-0.12
		90	-0.23	-0.09	-0.06	-0.17	-0.12	3.24	-1.19	-0.42	-0.52	-0.24	-0.03	-0.17
		91	-0.08	0.03	-0.01	-0.12	-0.22	2.21	-0.51	-0.44	-0.53	-0.16	-0.03	-0.14
		93	0.18	-0.01	0.02	-0.07	-0.09	1.15	-0.15	-0.30	-0.56	0.06	-0.23	0.00
		94	-0.01	-0.40	-0.11	0.03	0.35	1.47	-0.62	-0.60	-0.57	0.02	0.45	-0.01
1. Av. W.T. Fluctuation (m)			-0.052	-0.088	-0.052	-0.206	-0.022	2.172	-0.570	-0.488	-0.540	-0.110	0.044	-0.088
2. Groundwater Outflow (Ham)			-6.12	-10.35	-6.12	-24.24	-2.59	255.55	-67.06	-57.42	-63.53	-12.94	5.18	-10.35
3. Groundwater Balance (Ham)			43.31	32.96	26.84	2.60	0.01	255.55	188.49	131.07	67.54	54.60	59.78	-49.43
4. % Groundwater Balance			16.95	12.90	10.50	1.00	0.00	100	73.76	51.29	26.43	21.37	23.39	19.34
5. Cumulative Outflows (Ham)			-212.24	-222.59	-228.71	-252.95	-255.54	0.00	-67.06	-124.48	-188.01	-200.95	-195.77	-206.12

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 8: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S-2	4518	1	-0.33	-0.61	-0.55	-0.66	6.81	0.08	-1.59	0.42	-1.18	-0.83	-0.67	-0.89
		2	-0.45	-1.01	-0.91	-1.05	2.82	0.49	3.89	0.40	-1.34	-1.54	-0.81	-0.49
		3	-0.23	-0.29	-0.27	-0.43	0.98	0.13	1.83	0.16	-0.44	-0.73	-0.39	-0.32
		4	-0.25	-0.33	-0.35	-0.09	1.00	-0.37	1.43	0.06	-0.37	-0.30	-0.26	-0.17
		5	-0.24	-0.34	-0.23	-0.01	0.59	-0.12	0.84	0.29	-0.15	-0.16	-0.28	-0.19
		6	-0.05	-0.23	-0.64	-1.50	1.46	-0.31	2.63	-0.09	-0.39	-0.23	-0.32	-0.33
		7	-0.27	-0.32	-0.92	-1.08	1.51	0.92	2.29	0.72	-0.89	-0.55	-0.88	-0.53
		8	-0.23	-0.18	-0.18	-0.42	0.83	0.29	1.69	-0.15	-0.41	-0.54	-0.29	-0.41
		9	-0.09	0.00	-0.05	0.77	-0.15	0.78	1.73	-0.80	-0.43	-0.66	-0.88	-0.22
		10	-0.08	-0.29	-0.05	0.11	0.00	0.52	1.11	1.10	-1.22	-0.61	-0.36	-0.23
		11	0.03	-0.27	-0.06	0.01	0.44	-0.53	1.28	0.15	-0.37	-0.48	-0.26	-0.06
		12	0.10	-0.18	-0.03	-0.17	0.52	-0.34	1.45	0.21	-0.41	-0.42	-0.45	-0.28
		13	-0.15	-0.22	-0.19	2.77	-2.90	3.51	2.33	0.33	-2.75	-0.20	-2.11	-0.42
		14	-0.03	-0.16	-0.26	-0.18	0.75	-0.63	1.75	0.01	-0.35	-0.29	-0.46	-0.15
		15	-0.05	-0.31	-0.26	-0.02	0.42	1.64	1.12	0.88	-1.38	-0.25	-1.27	-0.52
		16	0.10	-0.01	-0.30	0.07	2.71	0.20	2.64	0.35	-2.23	-1.56	-1.39	-0.58

Continued…

Table: 8: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S-2	4518	17	0.00	-0.33	-0.63	-0.16	1.27	0.62	0.41	0.22	-0.68	-0.36	-0.15	-0.21
		18	-0.23	-0.15	-0.30	0.08	0.94	0.56	1.26	-0.02	-0.37	-0.68	-0.77	-0.32
		19	-0.39	-0.69	-1.07	0.12	2.39	0.05	1.28	0.11	-0.46	-0.65	-0.36	-0.33
		20	-0.12	-0.05	-0.04	-0.29	0.90	0.92	0.25	-0.37	-0.11	-0.99	0.07	-0.17
		21	0.05	-0.09	-0.03	-0.18	0.65	-0.74	2.07	0.10	-0.75	-0.57	-0.24	-0.27
		25	0.15	-0.32	-0.03	0.01	0.59	1.04	0.29	0.08	-0.34	-0.04	-1.02	-0.41
		26	-0.21	-0.19	-0.35	-0.17	0.49	0.46	0.47	0.03	-0.03	-0.08	-0.21	-0.21
		27	-0.16	0.07	1.38	-0.31	-0.13	0.76	-0.33	0.54	0.10	-0.33	-1.23	-0.36
		28	-0.01	-0.09	-0.56	0.20	0.75	0.54	0.30	0.06	-0.17	-0.35	-0.46	-0.21
		29	-0.14	-0.28	-0.29	0.23	1.21	0.91	0.36	0.28	-0.40	-0.26	-0.83	-0.79
		30	-0.10	-0.18	0.68	-0.76	0.70	0.79	0.62	-0.18	-0.36	-0.21	-0.15	-0.85
		31	-0.41	-0.12	-0.56	-0.21	9.40	-0.96	-1.86	-0.02	-0.83	-0.46	-3.42	-0.55
		32	0.33	0.00	-0.50	-0.01	0.70	0.09	1.03	0.19	-0.46	-0.26	-0.28	-0.83
		33	-0.28	-0.22	-0.17	-1.09	1.02	0.59	1.58	0.40	-0.75	-0.90	-0.14	-0.04
		34	-0.12	-0.22	-0.23	-0.04	1.68	-0.16	0.68	0.07	-0.69	-0.33	-0.21	-0.43
		35	-1.67	-0.70	-0.89	-1.14	4.04	3.88	4.88	0.17	-2.36	-0.30	-2.77	-3.14

Continued…

Table: 8: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S-2	4518	36	-0.04	-0.42	-0.80	-1.36	1.40	-0.44	2.74	0.03	-0.38	-1.00	-0.06	-0.10
		37	-0.50	-0.81	-1.12	-0.09	2.14	1.02	1.67	-0.16	-1.10	-0.52	-0.88	-0.69
		38	-0.71	0.77	2.25	0.13	0.72	1.01	0.63	-0.15	-0.77	-0.83	-0.11	-0.31
		39	-0.41	-0.07	0.27	-0.55	7.85	-3.70	-1.00	-0.37	-0.96	-0.08	-0.25	-0.14
		40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		41	0.38	-0.55	-0.33	-0.32	0.63	0.12	1.29	-0.01	-0.24	-0.73	0.05	-0.29
		42	-0.44	-0.07	0.03	-0.07	0.40	0.61	0.67	0.54	-0.68	0.00	-0.50	-0.49
		43	-0.06	-0.70	0.26	-0.15	1.05	0.44	2.05	0.06	-0.55	-0.29	-1.09	-1.02
		44	-0.09	-0.25	-0.12	-0.31	0.76	0.36	1.15	0.27	-0.54	-0.45	-0.43	-0.35
		45	-0.52	-0.13	-0.33	-0.19	0.87	0.52	0.95	0.51	-0.83	0.05	-0.55	-0.35
		46	-0.19	-0.55	-0.07	-0.47	1.00	0.94	1.25	0.13	-0.46	0.04	-1.38	-0.24
		47	0.05	-0.17	-0.35	-0.77	0.92	0.34	1.21	-0.18	-1.17	0.37	-0.06	-0.19
		48	0.31	-0.29	-0.38	-0.62	0.40	0.85	1.66	0.15	-0.79	-0.96	-0.16	-0.17
		49	-0.67	-0.25	-0.29	-0.27	0.97	0.80	1.68	0.23	-1.04	0.17	-0.49	-0.84
		92	-0.05	-0.03	0.05	-0.07	-0.20	3.06	-1.15	-0.5	-0.56	-0.47	0.02	-0.10
		99(1)	-	-	-	-	-	1.31	-0.59	-0.19	-0.31	-0.16	0.00	-
		106(8)	-	-	-	-	-	2.48	-0.68	-0.59	-0.50	-0.27	-0.14	-
1. Av. W.T. Fluctuation (m)			-0.169	-0.237	-0.195	-0.214	1.266	0.487	1.024	0.105	-0.651	-0.409	-0.563	-0.404
2. Groundwater Outflow (Ham)			-33.60	-47.15	-38.76	-42.54	251.67	96.81	203.56	20.87	-129.41	-81.31	-111.52	-80.31
3. Groundwater Balance (Ham)			136.76	89.65	50.89	8.35	251.67	348.48	552.04	572.91	443.5	362.19	250.67	170.36
4. % Groundwater Balance			20.87	15.65	8.88	1.46	43.92	60.83	96.36	100	77.41	63.22	43.75	29.74
5. Cumulative Outflows (Ham)			-436.16	-483.27	-522.03	-564.57	0.00	0.00	0.00	0.00	-129.41	-210.72	-322.25	-402.56

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 9: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S-3	3034	22	-0.10	0.25	-0.43	-0.14	0.74	2.27	-0.33	-0.16	-0.73	-0.28	-0.93	-0.16
		23	-0.72	-0.03	-0.34	0.50	0.02	4.56	-0.06	0.94	-2.37	0.84	-1.73	-1.61
		24	-0.16	0.45	-0.61	-0.09	0.77	2.53	0.01	-0.23	-1.05	0.22	-1.21	-0.63
		100(2)	-	-	-	-	-	1.75	-0.51	-0.35	-0.24	-0.17	-0.12	-
		101(3)	-	-	-	-	-	1.67	0.00	-0.43	-0.63	-0.22	-0.07	-
		102(4)	-	-	-	-	-	2.11	-0.09	-1.04	-0.23	-0.11	7.59	-
		103(5)	-	-	-	-	-	3.51	-1.22	-0.32	-0.22	-0.29	-0.02	-
		104(6)	-	-	-	-	-	4.03	-0.25	-1.01	-0.77	-0.67	-0.65	-
		105(7)	-	-	-	-	-	5.45	-1.36	-0.69	-1.36	-1.29	0.52	-
		107(9)	-	-	-	-	-	1.18	-0.42	-0.03	-0.23	-0.10	-0.11	-
		109(11)	-	-	-	-	-	2.59	-0.66	-0.81	-0.45	-0.64	-0.08	-
		112(14)	-	-	-	-	-	2.46	-0.16	-0.13	-0.20	-0.56	-0.23	-
		113(15)	-	-	-	-	-	2.11	-0.65	-0.24	-0.28	-0.37	-0.25	-
		114(16)	-	-	-	-	-	4.76	-0.69	-1.37	-0.99	-1.11	-0.09	-
		115(17)	-	-	-	-	-	0.49	0.00	-0.09	-0.08	0.00	-0.10	-
		116(18)	-	-	-	-	-	3.57	-1.27	-2.81	-0.26	-0.02	-0.30	-
1. Av. W.T. Fluctuation (m)			-0.327	0.223	-0.460	0.09	0.51	2.815	-0.479	-0.548	-0.631	-0.298	0.139	-0.800
2. Groundwater Outflow (Ham)			-43.65	29.77	-61.41	12.02	68.08	375.79	-83.94	-73.16	-84.24	-39.78	18.56	-106.80
3. Groundwater Balance (Ham)			-17.22	12.55	-48.86	-36.84	31.24	375.79	311.85	238.69	154.45	114..67	133.23	26.43
4. % Groundwater Balance			-4.58	3.34	-13.00	-9.8	8.3	100.00	82.99	63.52	41.10	30.51	35.45	7.03
5. Cumulative Outflows (Ham)			-393.01	-363.24	-424.65	-412.63	-344.55	0.00	-63.94	-137.1	-221.34	-261.12	-242.56	-349.36

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

Table: 10: Details of monthly groundwater balance computation based on water table fluctuation method

Watershed Code	Area (Ha.)	Well no.	Monthly groundwater level fluctuations (m) for 2003											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S-4	661	108(10)	-	-	-	-	-	1.07	-0.44	-0.22	-0.10	-0.15	0.01	-
		110(12)	-	-	-	-	-	2.03	-0.85	-0.48	-0.18	-0.44	-0.02	-
		111(13)	-	-	-	-	-	2.70	-1.53	-0.06	0.17	0.18	-0.44	-
1. Av. W.T. Fluctuation (m)			-	-	-	-	-	1.933	-0.940	-0.253	-0.037	-0.137	-0.15	-
2. Groundwater Outflow (Ham)			-	-	-	-	-	56.22	-27.34	-7.36	-1.08	-3.98	-4.36	-
3. Groundwater Balance (Ham)			-	-	-	-	-	56.22	28.88	21.52	20.44	16.46	12.1	-
4. % Groundwater Balance			-	-	-	-	-	100	51.37	38.28	36.37	29.28	21.23	-
5. Cumulative Outflows (Ham)			-	-	-	-	-	0.00	-27.34	-34.7	-35.78	-39.76	-44.12	-

Groundwater Inflows (+Q) and Outflows (-Q) are computed using the following equation:

Q (Ham) = Watershed Area (Ha.) x Average Water Table Fluctuation (m) x Aquifer Specific Yield (S_Y)

The average specific yield value of 0.044 has been used in the present computation, which is derived from the distributed values obtained from pumping test data analysis in the study area.

EXISTING GROUNDWATER ESTIMATION METHODOLOGY AND ASSOCIATED PROBLEMS

Generally the groundwater reserves in the unconfined aquifers are estimated using a well-known method known as water table fluctuation method using the expression;

Area of the watershed x Water table fluctuation x Specific yield of the aquifer ...(1)

In this method three parameters viz., the watershed area, groundwater level fluctuation value and specific yield of the aquifer are required to be known. Among the above three required parameters of the groundwater balance estimation, watershed area and groundwater fluctuation can be measured with high precision. However, the accuracy and determination of the aquifer specific yield is generally inaccurate because its accuracy and adequacy is influenced by;

1. The financial aspects involved in conducting the elaborate and numerous aquifer tests.
2. Aquifer homogeneity, if the aquifer under question is inhomogeneous large number of tests need to be conducted which increases the requirement of funds and time.
3. Accessibility of the area, as generally aquifer tests are conducted on the existing open wells and if the wells where the parameters are to be estimated are inaccessible for some reasons then the tests can not be done.
4. Non-uniqueness in the results of aquifer test data analysis. Quite some times the specific yield values vary from one method of analysis to other in such instances average values are to be adopted which itself may not be accurate.

The above mentioned equation is straightforward and simple but can be dangerous to use because out of the three parameters used in the expression one parameter that is the reliable values of aquifer specific yield is fairly difficult to obtain at all places of interest. In general it is a common practice to use text book values derived from relational tables or use average values from distributed parameters. Under these circumstances the computed groundwater balance values can be misleading to any magnitude.

The influence of specific yield values on groundwater balance computation can be visualized by computing groundwater balance for a hypothetical watershed. Let us assume a watershed area of 100 hectares and an average annual groundwater level fluctuation of 2m. Using the above expression the groundwater balance volumes have been computed for different assumed values of specific yield as shown in the following table. The plot of groundwater balance verses specific yield for this case is shown in the following figure.

S.no.	Watershed Area (Hectors)	Average annual groundwater level fluctuation (m)	Aquifer Specific Yield values (fraction)	Computed groundwater balance (Ham)
1	100	2	0.1	20
2	100	2	0.01	2
3	100	2	0.001	0.2
4	100	2	0.0001	0.02
5	100	2	0.00001	0.002

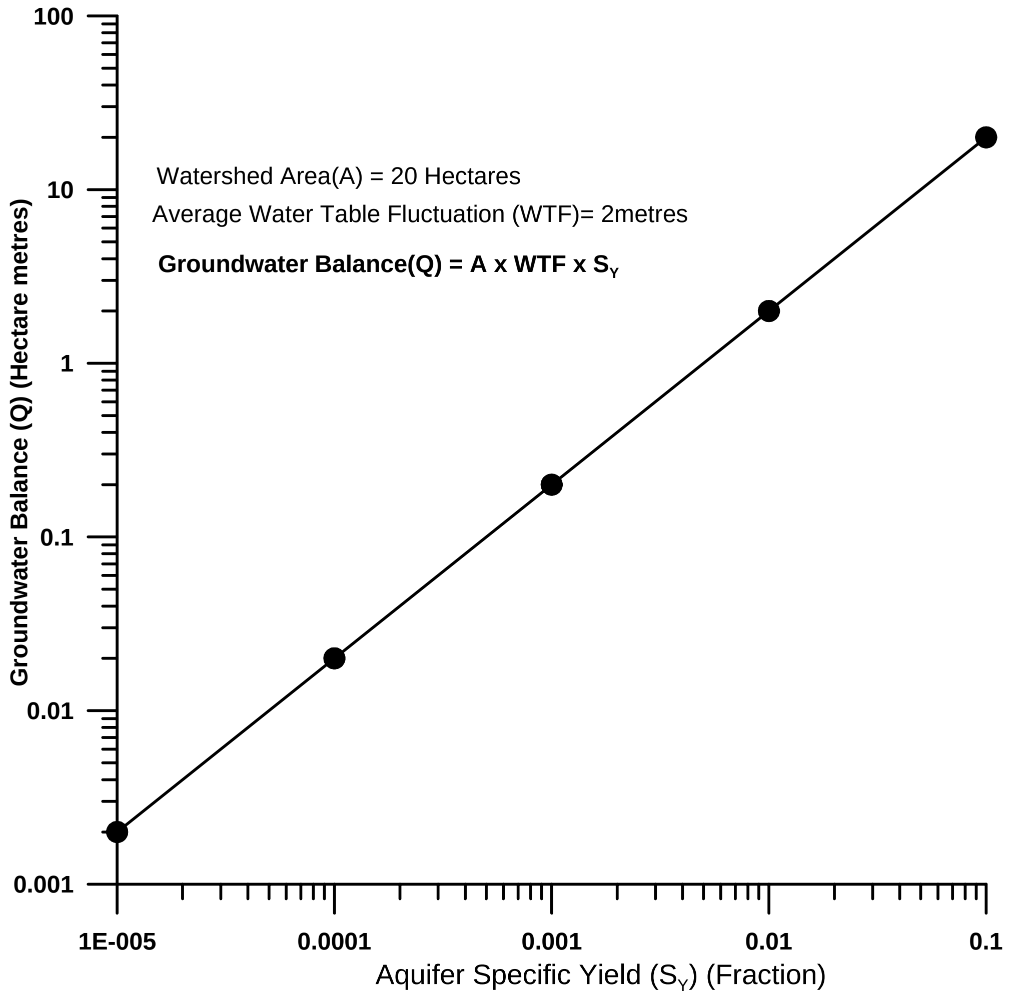


Fig-6:Relation between aquifer specific yield and the computed groundwater storage

RAINFALL RECHARGE ESTIMATION FOR THE STUDY AREA

General

Aquifer recharge is an important component of the hydrological cycle. Recharge quantification not only helps in groundwater potential estimation but also helps in the determination of aquifer vulnerability to pollution. Recharged water transports a contaminant vertically to the water table and horizontally within the aquifer. Also the quantity of water available for dispersion and dilution of the contaminant in the vadose zone and in the saturated zone is controlled by recharge rate and quantity. In general, one can say that larger the recharge, larger is the potential for groundwater pollution as the contaminants are moved at a faster rate in a larger quantity, if the contaminant source is unlimited. On the other hand, larger quality of groundwater recharge can cause larger dilution and dispersion and thus decrease the pollution potential, if the contaminant source through which recharge is taking place is limited in quantity (Aller, et al., 1987). Therefore, it is pertinent to estimate the reliable quantity and rate of aquifer recharge.

Methodology of recharge estimation for the study area

Using daily sequential water balance model BALSEQ, **Chachadi et al. 2004** have estimated the rainfall recharge values for different land use classes in the mining belt of North Goa. The input data and the results of the computation carried out by them for mining areas in North Goa are shown in the following **Tables 5 and 6.** The unit values of aquifer recharge (% of rainfall as recharge shown in the last column of Table 6) derived for each land use class by the model has been adopted for the computation of aquifer recharge in the present study area. Therefore by using the area under each land use class and the adopted unit recharge values, groundwater recharge computed is given in **Table-7.**

Annexure-2

STATUS OF GROUNDWATER RECHARGES AND AVAILABILITY IN THE MINING WATERSHEDS OF NORTH GOA, GOA

B. S. Choudri[1] and A.G. Chachadi[2]

ABSTRACT

The intense opencast iron ore mining in North Goa has induced significant changes in water quality and quantity. In the present paper a detailed account on the status of groundwater recharges and the availability has been presented. The study has been carried out on 10 sub-watersheds, which are subjected to most intense mining operations. A comprehensive account of groundwater status has been reported for the first time, which would help planners to take necessary corrective measures to overcome the problems.

1. General

Water stress conditions arise when the quantity of groundwater extracted exceeds the recharges resulting in overall severe water shortages in the watershed. Depending on the magnitude of this imbalance between total extractions and recharges the watershed can be classified into four categories (modified from CGWB, 1984) viz., **non-critical (White; <50% groundwater is developed), sub-critical (Gray; 50% to 75% groundwater is developed), critical (Black; 75% to 100% groundwater is developed) and most critical (Red; over exploitation of groundwater).** No groundwater development activity is allowed in the watersheds in critical and most critical category areas where groundwater extractions exceed 75% of the mean annual recharge. When the groundwater extractions are less than 50% of the mean annual recharge the area is categorized as non-critical and no restrictions on groundwater extractions are imposed in such watersheds. In the watersheds where the total groundwater extractions balance mean annual recharge a cautious approach is adopted in the groundwater development. Therefore water stress status of a watershed is an important parameter in the decision making process regarding groundwater development.

[1] The Energy and Resources Institute, WRC, Panaji, Goa, Email: bchoudri@teri.res.in

[2] Department of Earth Science, Goa University, Goa-403 206, Email: chachadi1@rediffmail.com

It is usually much wiser to strike a balance between groundwater extraction and availability at a high level of groundwater heads than at low levels (Teresa and Lobo - Ferreira, 2002). First of all, the high levels provide flexibility for temporal overdraft and therefore supply safety. Secondly, the cost of pumping is lower, as the water levels are at shallower depths from the ground. Thirdly, the adverse impacts on groundwater regime are not inflicted such as seawater intrusion, pollutant mixing etc. In dry regions bigger rainstorm events with non-negligible replenishment of groundwater reservoirs may happen rarely and at long time intervals. Sustainable use then means that within this period a balance between recharged and extracted volumes must be reached. In the years without effective replenishment, groundwater can be extracted if it can be assumed that till the next recharge event enough water remains in the reservoir to satisfy the basic needs. In other words in the context of groundwater management, sustainability implies a limitation of the extraction rate to a value below the long-term natural replenishment rate. There are, however, additional aspects to sustainability such as (Kinzelbach and Kunstmann, 1999):

- The limitation of groundwater table drop to a level, which is compatible with vegetation needs in the adjoining areas. This is very relevant in Goa as many agricultural and horticultural lands are close to dewatering mine pits that drain possibly out the soil moisture to a level whereby the crops/vegetation starts wilting.
- The guarantee of minimum flow rates in downstream drainage basins.
- The prevention of seawater intrusion or salt-water up coning.
- The prevention of long-lasting pollution, land-subsidence, and soil salinisation.

Under natural undeveloped conditions the groundwater regime is in dynamic balance with recharges equaling the discharges. However, any anthropogenic activity would change this natural balance between the recharges and discharges. Mining is one of such activity wherein invariably the groundwater regime is disturbed. The groundwater quantity and quality in such areas may get affected at different intensities depending on the magnitude of the activity and intensity of interference into the groundwater regime. Groundwater withdrawals for domestic use and normal agricultural activity may not offset the groundwater balance to a significant level as recharges balance such small changes under normal rainfall conditions. However, if large-scale activities like dewatering of the mine pit is introduced in the watershed as in Goa then it is but natural that the groundwater balance in the watershed may get offset. There may be deficit or surplus groundwater balance depending on the recharge and water use practices in the area. It is possible to assess a particular watershed for its groundwater balance.

2. Existing groundwater estimation methodology and associated problems

Generally the groundwater recharges in an <u>unconfined aquifer</u> are estimated by <u>water table fluctuation method</u> using the expression;

$$\mathbf{R = A \times \Delta s \times S_Y} \qquad \ldots(1)$$

where,

R = recharge to groundwater (L^3),

A = area of the watershed (L^2),

Δs = groundwater level change or fluctuation (L), and

S_Y = specific yield (fraction) of the unconfined aquifer.

In this method the three parameters viz., the watershed area, groundwater level fluctuation and specific yield of the aquifer are required to be known. Among the above three required parameters of the groundwater balance equation, watershed area and groundwater level fluctuation can be measured with good precision. However, the accuracy and determination of the aquifer specific yield is generally inaccurate because its accuracy and adequacy is influenced by several factors including economic aspects of expensive field experiments.

The above mentioned equation is straightforward and simple but can give erroneous results due to inadvertent use of unreliable values of aquifer specific yield. In general it is a common practice to use text book values derived from relational tables or use average values from distributed parameters. Under these circumstances the computed groundwater volumes can be misleading to any magnitude.

Besides the above constraints the measured groundwater levels in the unconfined top aquifer may be influenced by the leakage taking place to the deeper aquifers which may lead to lower change in water table levels in the top aquifer. The local pumping and other anthropogenic and natural withdrawals/outflows while taking the water level measurements also invariably influence values of groundwater levels. Therefore corrections to this measurement are not possible to apply while computing the recharges. It is therefore wise to use these recharge values as only approximations for any planning purpose. The best way therefore is to adopt some direct method of estimating the rainfall recharge to ground as all groundwater is mainly derived from this source.

3. Objective of the present study

The North Goa district has been witnessing a rapid growth in the mining related activities in the recent past. There has been feeling among the local community of the mining district that the groundwater reserves in the vicinity of the mining areas have been declining. Therefore there is need to assess the current status of groundwater in order to find the reasons of so called decline in groundwater reserves in these areas. The study results would ultimately be instrumental in taking appropriate corrective measures to overcome groundwater overdrafts if any in the mining watersheds.

4. Study area location

The study area located between Sirigao in the Northwest to Surla-Velguem in the Southeast has been chosen keeping in mind the high intensity and aerial extent of mining activity. The total area covered in the study is about 194 km^2. The entire area is divided into 10 sub-watersheds (B-1 to B-6 and S-1 to S-4) varying in area from 4 km^2 to 45 km^2 (**Fig. 1**). The area falls mainly in talukas of Bicholim and sattari. All the major mining companies have their working leases in this belt. The well known villages coming in the mining belt include Sirigao, Lamgao, Mulgao, Mayem, Piligao, Bicholim, Sanquelim, Cudnem, Honda, Pissurlem, Sonshi, Surla, and Velguem.

5. Evaluation of rainfall type and variation in the study area

Attempt has been made to study the rainfall pattern variation over the study area because the major part of the study area is spread in the East-West direction and it is seen that the rainfall varies considerably from West (Coast) to East (Inland). The long-term average annual rainfall for four rain gauge stations viz., Panaji, Mapuca, Bicholim and Valpoi were chosen and plotted on a linear scale with distance from the coast. The approximate ground elevations above sea level estimated from the topographical maps at the corresponding rain gauge stations were also plotted. The plot is shown in **Fig.2.** As seen from the plot it is clear that the rainfall increases linearly from Coast to inland. The positive correlation between topographical elevations of the place and the rainfall also indicates the predominance of orographic type of precipitation in the study area.

The non-monsoon rainfall contribution varies from 2.7 to 3.9 percent of the annual rainfall over Goa. The distribution of normal annual monsoon rainfall for the entire State of Goa has been plotted and shown in **Fig.3**. As seen from the figure the rainfall increases from coast towards the eastern side consisting of Western Ghats indicating orographic type of precipitation. The rainfall contours (isohyets) remain parallel to the coast.

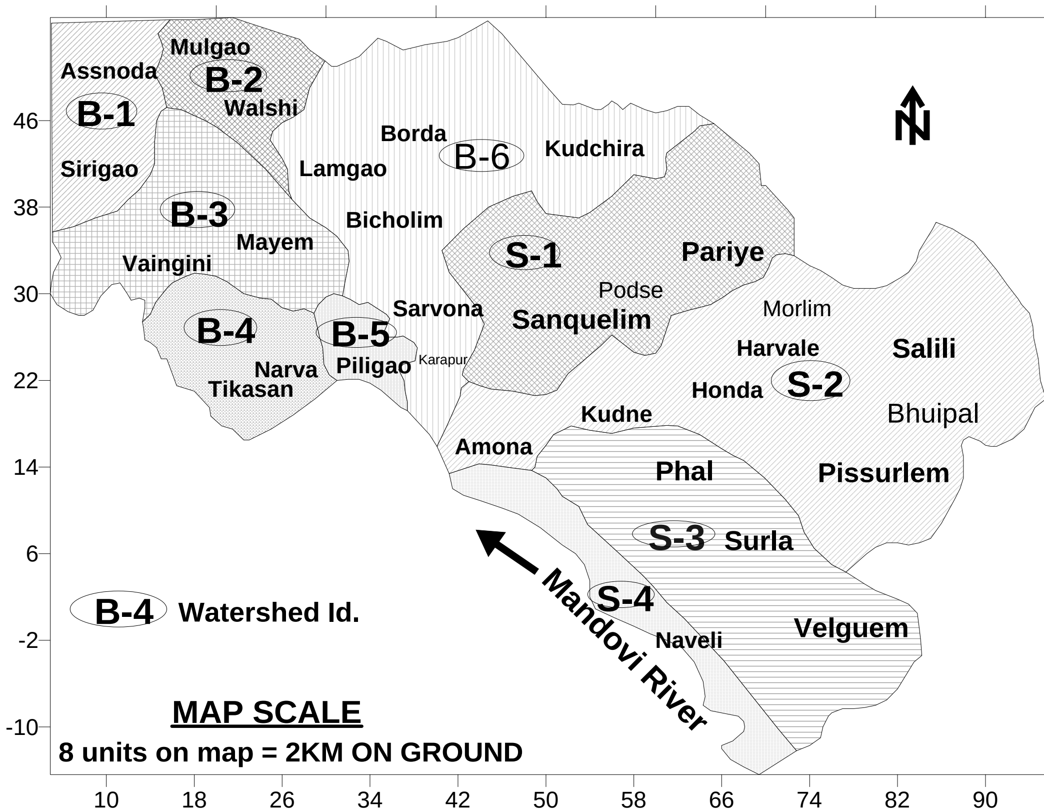


Fig.1: Location map of sub-watersheds in the north Goa mining area

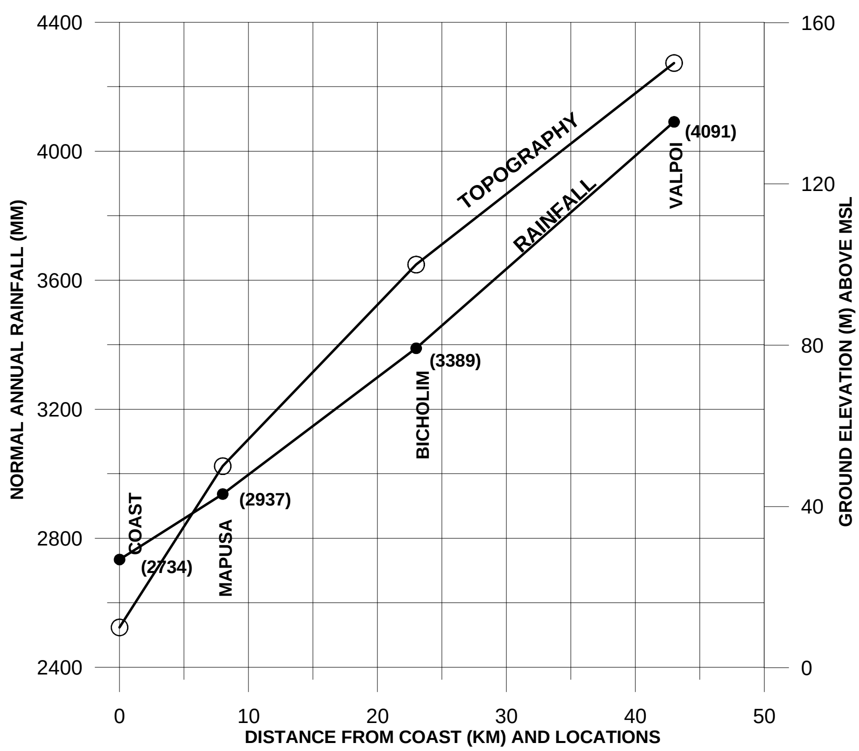


FIG. 2: RAINFALL & TOPOGRAPHICAL VARIATION ALONG MAPUSA-BICHOLIM-VALPOI PROFILE

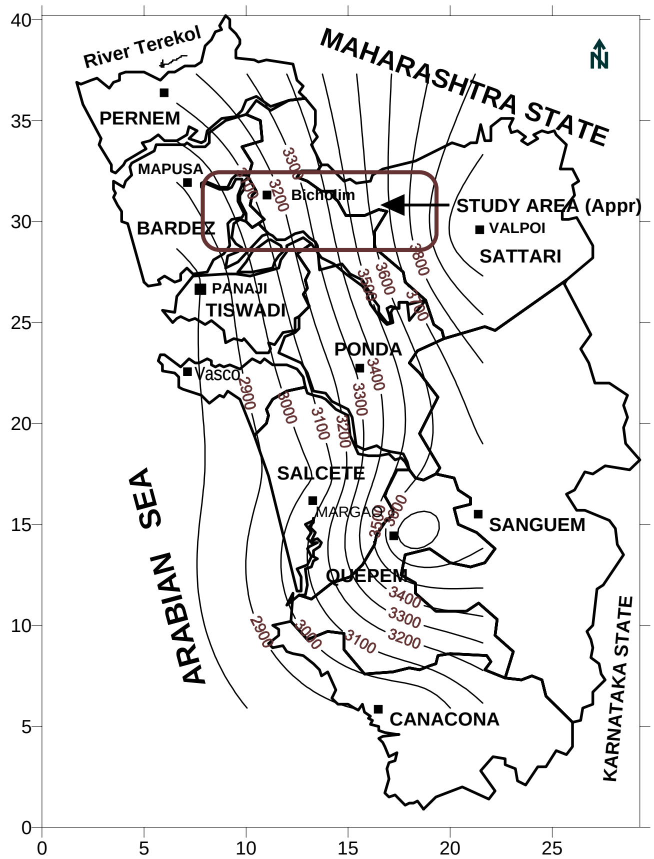


FIG.3: NORMAL MONSOON RAINFALL(MM) DISTRIBUTION OVER GOA

5. Aquifer types in Goa

The comprehensive exploratory drilling by Central Ground Wwater Board (CGWB), State Groundwater Agency and groundwater related studies by other academic and private organizations have provided sufficient data for classification of the aquifers in Goa. Chachadi (2002) has classified the main aquifers into the following five types:

1. **Under Lateritic Plateaus without Ore Body:** Plateaus are most common topographical features confined to midlands and the coastal plains of Goa. These plateaus are generally made of flat-topped elevated landmasses to about 40 to 80m height above sea level. Generally they are covered with hard some times-massive laterite on the flat portion and bouldary detrital laterites on the slopes. These detrital laterites are the transported masses and are embedded in lateritic soils. These slopes are covered with evergreen vegetation made up of variety of fruit bearing plants. Most of the rural and urban settlements are found along the slopes of these plateaus. A typical

non-ore-bearing plateau is shown in **Fig.4.** The laterites vary in thickness from less than 5m to more than 30m and these are underlain by a thick sequence of lithomarge (lateritic) clay. The boundary between the lithomarge clay and the fractured and weathered basement rock often made of phyllites and metasediments form an important confined aquifer. The ground water in the fractured deep aquifer under the coastal plateaus is often found below sea levels. The laterite located on the plateaus does not generally form aquifers because they cannot hold water mainly due to their topographical settings. The intervening lithomarge clay is not totally impermeable it can store and vertically transmit significant quantity of water through it, which enhances the storage in the lower confined aquifer. The confined aquifer also gets its recharge from lateral directions through the low-lying alluvial plain areas around the plateaus. The most interesting feature of the plateaus in Goa is the presence of natural springs around the slopes. These are the lifelines of the rural water needs. The rainwater when enters the laterites which are porous and fractured will move along the contact zone between low permeable lithomarge clay and bottom of the overlying laterites to emerge as a spring along the slope. Many open wells, streams and even bore wells located in the low lying flat areas around the plateaus are fed by these springs.

2. **Under Lateritic Plateaus Having Iron Ore Body:** Majority of the mineral deposits of Goa region are located below the hilly plateau areas ranging in elevation from few meters to over 100m above msl in the mid land areas. These plateaus are composed of lateritic cover followed by a thick layer of various clays. Intervening these clays are the iron and manganese ore bodies located mainly in the form of powdery ores and lumps. Hydrogeologically these plateaus act as rainfall recharge areas for local groundwater regime. The rain percolates through the fractured laterites and underlying clays. The resulting water table is much above the surrounding plain area and quite often the water table intersects the ground surface at the hill slopes resulting in

springs. A typical cross section of the area in the mining belt is shown in **Fig.5** with the iron ore deposits and the hydrological components.

In order to win the precious iron ore the mining activity has to be done by cutting the top lateritic cover on the plateaus and removing the clay overburden. This process not only eliminates the rainwater recharge area forever but also the water table position in surrounding low lying areas declines due to non-availability of recharge area. This leads to drying up of the springs, wells and even streams located along the hill slopes. The mining activity also induces groundwater flow into the mine pit from both unconfined lateritic layer and the confined iron ore aquifers during mining. This water has to be pumped out to provide the dry conditions at the mine bottom for ore extraction.

3. **Under the Plains Covered with Laterites:** Laterites are widespread rock types occupying large aerial extent in Goa. In the plain lands of the midland and in some coastal areas the laterites form very good phreatic aquifers due to the presence of good porosity and fractures. These laterites can sustain groundwater for long durations. They are recharged annually through rainfall. Large numbers of open wells are found in these laterites. The yields from these wells are some times quite high nevertheless these wells located in the laterites meet large water requirements of the people. These laterites like the plateau ones are also underlain by a fairly thick sequence of lithomarge clay and this clay terminates below at the fresh rock at depths. These fresh rocks quite often are weathered and fractured and hence form a confined aquifers. Dependable and sustainable well yields can be achieved by drilling bore wells through these fractured basement aquifers.

4. **Under Alluvial Plains:** Particularly in the coastal zone large tracts of land are covered with river, coastal and intermountain valley deposits. These are alluvial sediments composed of varying amounts of sand, clay and silt. The thickness of these alluvial sediments also varies largely depending on the basement rock topography. The coastal alluvium is the most permeable having primary porosity and it get recharged very quickly and is also highly

drainable in nature. These alluvial sediments grade into weathered laterites, which in turn rest on fresh parent rock, which are often fractured. These alluvial aquifers are very sensitive to pollution and they cannot hold water in large quantities for longer periods due to their typical hydrogeological characteristics. The alluvial aquifers are therefore not sustainable sources of fresh groundwater. The deeper aquifers in the basement rock are confined in nature and are generally tapped by bore wells. The Phreatic alluvial aquifers are commonly reached through open wells of varying dimensions. Most of the coastal alluvial aquifers are contaminated by indiscriminate disposal of septic tank and cesspool wastes besides sewages from hotels and municipalities (Chachadi, 2001). Near the coast these aquifers are subjected to seawater intrusion due to over pumping for various activities.

5. **Aquifers in Crystalline Rocks:** In the highlands of Sahyadris and granitic terrains in south Goa the groundwater is found in the fractured and weathered mantle of these rocks. Unconfined to confined conditions are encountered. Deep-seated fractures give rise to confined water bodies and are recharge by rainwater.

6. Groundwater recharge and discharges

In Goa the main source of recharge to groundwater is from south-west monsoon which spans over a period of nearly four months between June and September. The rainfall varies from about 2500mm along the coast to about 4500mm towards the Western Ghats. The magnitude of recharge to groundwater also varies from place to place depending on the nature of the surface conditions. Chachadi et al (2004) have estimated the rainfall recharge to groundwater using daily sequential water balance method (BALSEQ) for various land uses in the coastal and mining belts of Goa. The water levels in the wells generally reach to the peak levels during the month of July/August under normal rainy season. However, studies in the coastal alluvial belts indicate that the groundwater recharges at a much faster rate due to high permeability of the surface soils. The groundwater in the coastal plains also drains at a faster rate to the sea.

The groundwater in the state is mainly used for drinking and industrial purposes followed by agriculture to some extent. The groundwater development vis-à-vis balance in the state varies from place to place. In the coastal belt at most of the locations there is a state of overdevelopment in groundwater. This is partly due to natural drainage of groundwater to the sea besides human consumption, which is highest along the coast due to very high population density and industrial withdrawals. At few locations in the mining belts there is an over developed condition mainly due to dewatering from the mine pits and mine reject dumping as many of the mines have to operate below the local water table/piezometric levels.

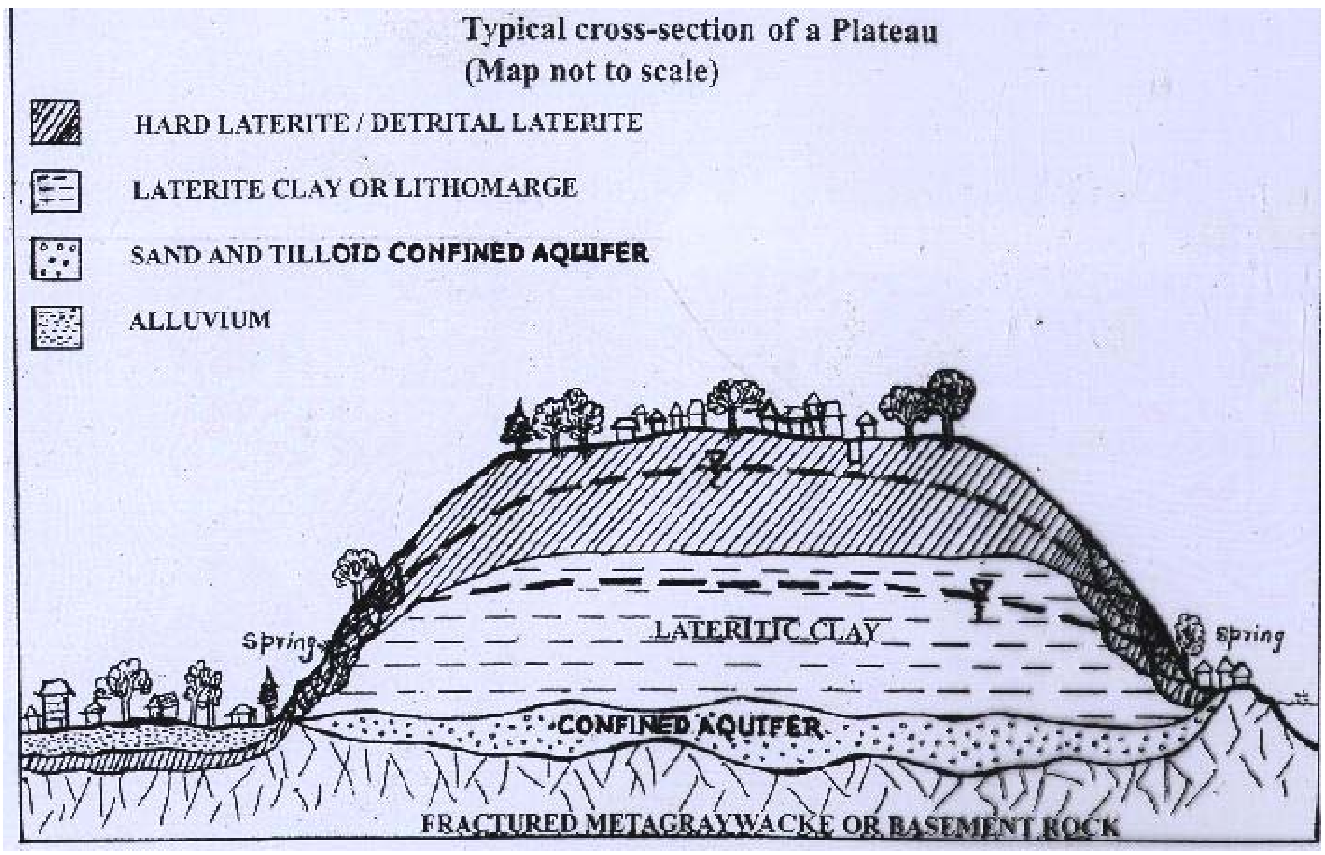


Fig. 4. Occurrence of groundwater below lateritic plateau in

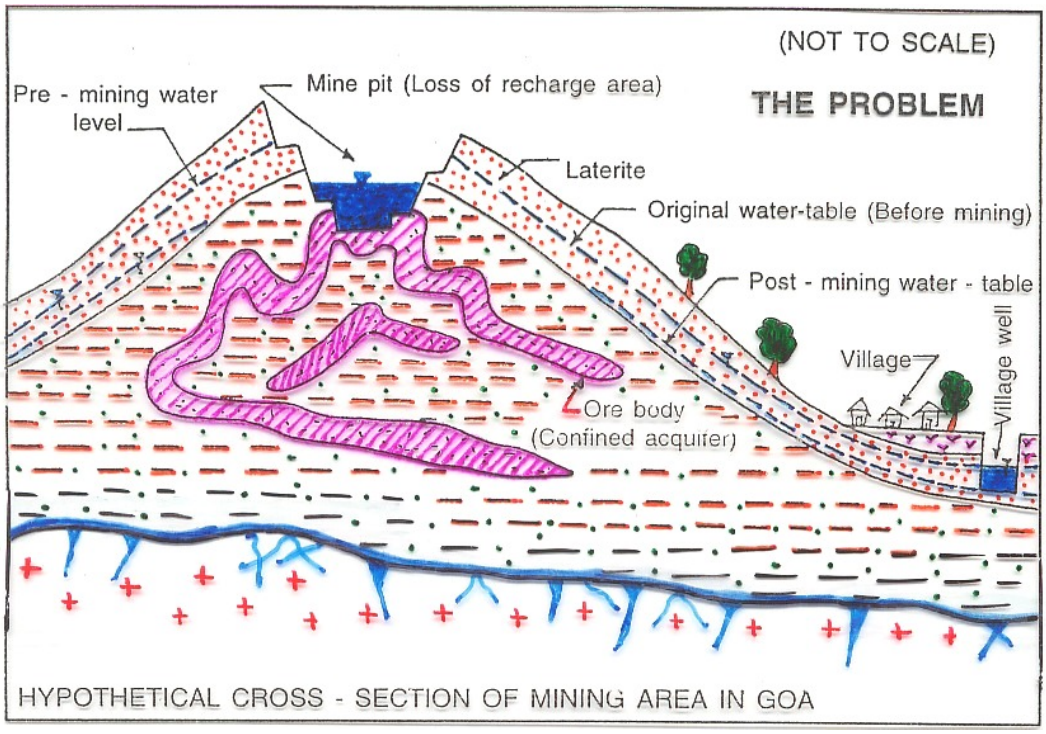


Fig. 5: Typical cross-section across a Plateau in mining area

7. Studies of groundwater flow-net analysis in the ten-mining watershed in north Goa

A flow net is a sketched representation of the flow paths taken by water molecules through the subsurface. The “grid” of a flow-net is comprised of flow-lines (idealized paths followed by water molecules in moving from position of high hydraulic gradient to those of lower head represented by smooth curves at right angles to equipotential lines) and equipotential lines (lines along which the hydraulic head is equal). Flow-net is a very powerful analytical tool for studying the groundwater behavior. Flow-nets may be constructed by a number of procedures including trial-error sketching; physical modeling, electrical analog method, and computer assisted mathematical modeling.

In the present study manual as well as computer assisted (SURFER) flow-net sketching has been adopted. The input to the SURFER program includes X and Y co-ordinates of observation wells and water level data above mean sea level (msl) in meters (Z co-ordinate). The catchment boundary is plotted using X and Y data manually sampled from the base map along the boundary. The flow-net contour maps for the months of May and June 2003 has been constructed for all the ten watersheds. Kriging technique is used for plotting of various contours as it was found that it is the best-fit method for plotting of smooth contours (Vijay Kumar and Remadevi, 2003). For the sake of space constraint only one flow-net is shown in **Fig. 6.** In total 116-groundwater observation well network has been established in the study area. The location of the groundwater monitoring network stations is shown in **Fig.7.**

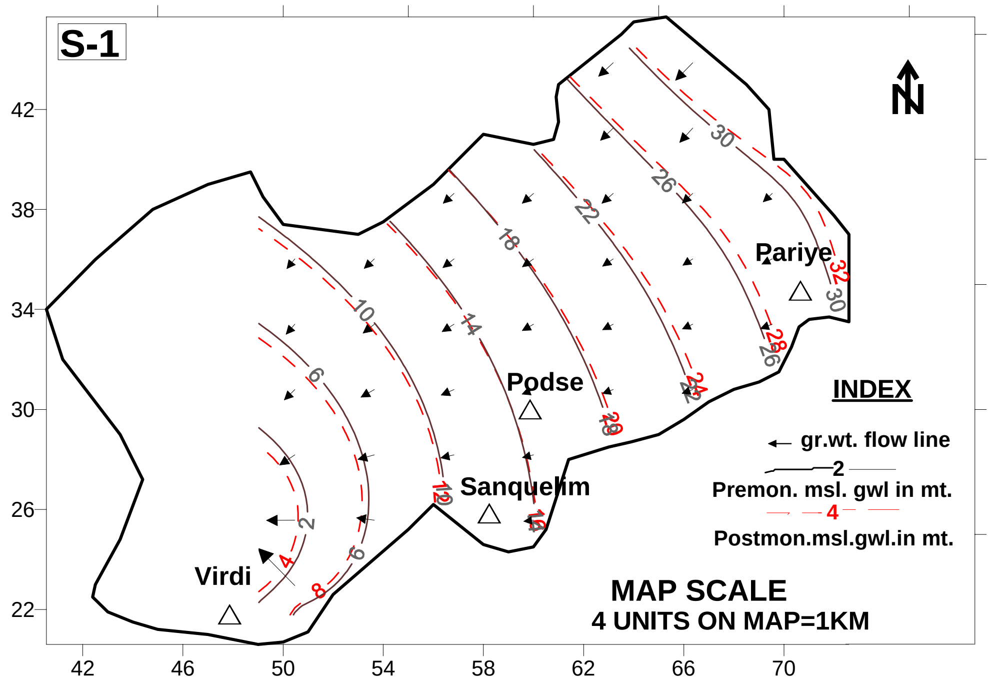


Fig. 6: Groundwater flow-net for the mining watershed

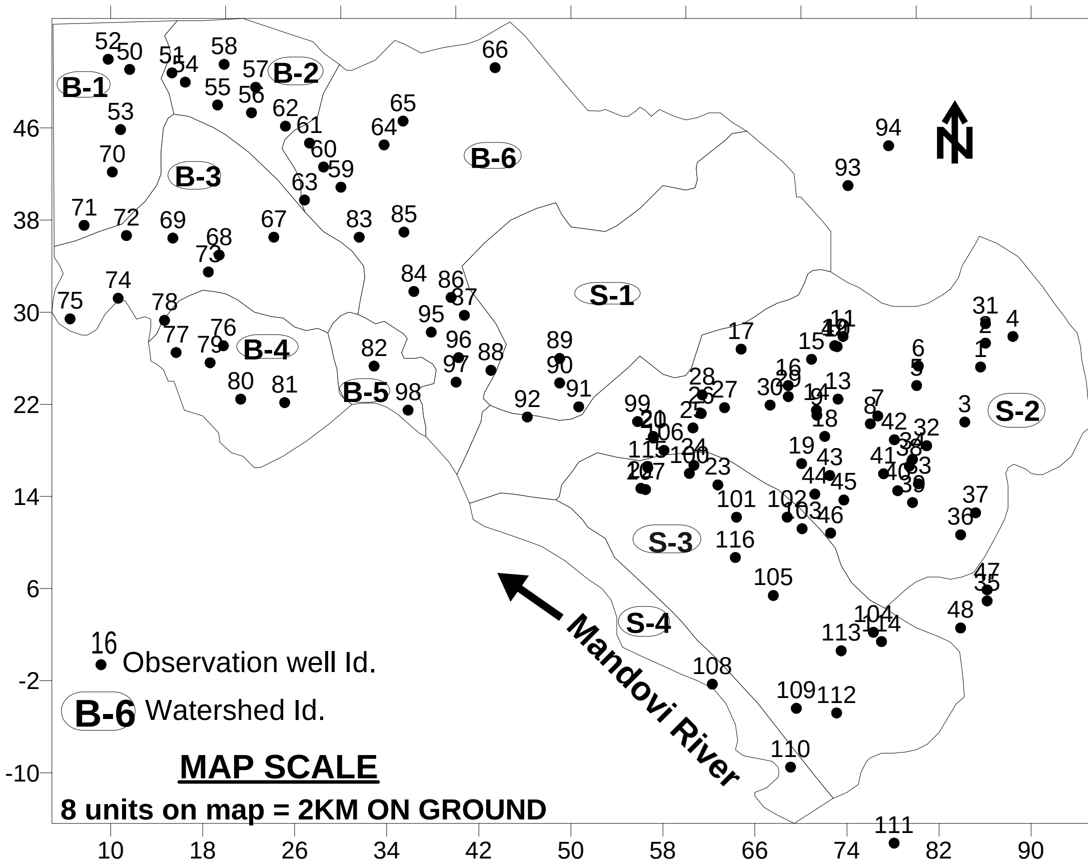


Fig. 7: Location of groundwater monitoring well network

8. Long term groundwater level changes through well hydrograph studies

In watershed S-1 the monthly groundwater level data of 49 observation wells for a continuous period of 4 years was collected (The water levels are measured on monthly basis from April 1997 till March 2001, Chachadi, 2002). This data was used to construct the well hydrographs to ascertain the long-term behavior in the groundwater levels. The monthly normal rainfall is also plotted on each of the hydrographs for purpose of correlation and interpretation. A linear fit to the groundwater levels is fitted on all hydrographs to ascertain their behavior with time. All the 49 well hydrographs after careful reading were classified into the following three categories based on their groundwater level trends:

1. Hydrographs showing Increasing trends	38 nos.	77.6% of total
2. Hydrographs showing Decreasing trends	06 nos.	12.2% of total
3. Hydrographs showing no trends	05 nos.	10.2% of total

The well hydrographs from the study area indicate that the water levels in the phreatic aquifer respond prominently to rainfall recharge. There is a delay time of about one-month between rainfall peak and the shallowest ground water level. In most of the cases the ground water levels are restored to the base level (premonsoon level) long after the cessation of monsoon rainfall. The steep limb of the rising hydrograph indicate quick recharge to groundwater and on the other hand the gentle slope of the falling limb of hydrograph show slower drainage of the aquifer which is considered good for the health of the ground water regime. The quick rising limbs of hydrographs indicate a permeable rock/soil matrix in the top unsaturated zone. It is interesting to note that although both saturated and unsaturated rock matrix is made up of same lateritic rock having channel like pores the drainage of groundwater from the saturated zone becomes sluggish which could be due to gentle groundwater level gradients. On the other hand vertical flow of water from rainfall recharge is not inhibited by gradient problems. Majority of the hydrograph shapes is identical indicating presence of similar hydrogeological rock matrix in the area.

The phenomenon of decreasing groundwater level (**Fig.8**) is confined to the mining areas located in the upper reaches of the watershed, as the recharge to groundwater is limited at these locations. Majority of the well hydrographs (77.6%) from the study area shows rising trends in groundwater levels of varying magnitudes. This is infect a very interesting fact in the mining belt where large quantity of groundwater is being pumped out annually to win the ore from below the water table. An increasing trend in the hydrograph is an indication of surplus groundwater being retained in the subsurface year after year. It happens when annual recharges exceed annual discharges. Assuming natural recharges and discharges to remain unchanged it is only the recharges and changed pumping patterns of anthropogenic origin, which can cause such increasing trends in groundwater levels. The possible reasons for the rising groundwater levels in the present study area could be:

1. During mining excavations powdery iron ore bodies which form confined deeper aquifers in the area release large quantity of groundwater. This water along with the accumulated rainwater during four months of rain is pumped out to create the dry working conditions at the pit bottoms. After desiltation this pumped water is

let out to natural drains and streams. Farmers use some water for agriculture. Some water is put in the beneficiation plants for washing the ore and also for dust settling on the roads during summer months. All these uses provide for additional non-monsoon recharge to phreatic aquifers via return flow from agricultural lands, streambeds, settling ponds etc.

2. The ore to waste ratio is 1:3 in Goa. Annually around 30-35 million tones of mining rejects are being generated. These mining rejects are mostly clays, silts and low-grade powdery iron ores. Studies have shown that these rejects have fairly good hydraulic conductivity. The mine rejects are dumped mostly on the hill slopes and surrounding nearby places. As on today these reject dumps occupy large areas in the watershed. During four months of rains the rejects absorb and retain sizable amount of water in them and transmit it to the underlying phreatic aquifer over a period of time. This provides sustainable recharge to aquifers and hence could steadily raise the water table levels.
3. There are large number of abandoned mine pits of huge dimensions which are abandoned due to low grade ore or due to uneconomic working depths. These pits act as both collection ponds of rainfall surface-runoff and groundwater runoff during monsoon when water table levels are high. When they are full these pits act as point recharge sources to the phreatic as well as confined aquifers in the study area during rest of year. This could also add to the rising water table levels in the area.
4. Although small but important is the fact that day by day there is lesser dependence of people on groundwater to meet domestic needs as tap water from surface source is made available in most parts of the study area.
5. In order to minimize the silting of the streambeds mining companies have constructed several silt traps, which are the temporary brick walls across the streams carrying the mine discharges. These silt traps retain water behind them and allow for longer contact time with the ground. This process enhances the recharge to groundwater. Similar desilting ponds near the active mine pits also provide for additional groundwater recharge.

6. Any mining activity has to be preceded by drilling of large number (in hundreds) of exploratory boreholes of different depths. There are thousands of such exploratory boreholes in the Goa mining area. These bore holes cut across different litho-units and act as conduits connecting phreatic aquifers to the ground surface through which recharge from rainfall takes place even in areas on impervious surface layers.

There are 5 wells showing no trend change in the groundwater levels. It seems that although they are located in close proximity of active mines the groundwater levels are maintained due to balancing of recharges and discharge components of groundwater regime. The pumped pit water and wastewater from beneficiation plants recharges the groundwater regime and this recharge equals all the discharges and hence a balance is reached in the groundwater storage.

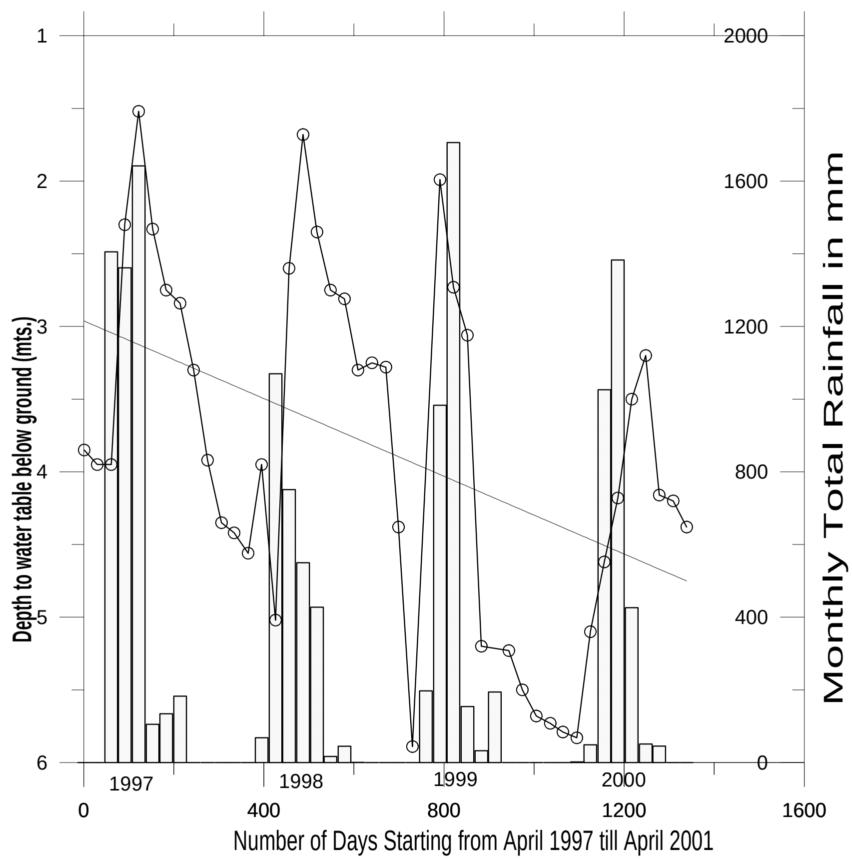


Fig.8. Well hydrograph and rainfall for well no.45 (falling water levels)

9. Groundwater balance of 10 mining watersheds and the current status of groundwater use

The water availability and use in the 10 mining watersheds has been worked out under the following heads:

1. Estimation of basin wise water requirement in the north Goa mining area based on sectoral demands including;
   i) domestic water requirements (Table-1)
   ii) irrigation water requirements (Table-2)
   iii) industrial water requirements (Table-3)
   iv) live stock water requirements (Table-4)
   v) requirements for wet beneficiation and ore washing (Table-5)
   vi) groundwater drafts from active mine pits (Table-6)

2. Estimation of basin wise groundwater recharge based on daily sequential water balancing (**BALSEQ)** model.

3. Estimation of basin wise groundwater draft in the mining area of north Goa and groundwater balance.

I. ESTIMATION OF BASINWISE WATER REQUIREMENT IN THE NORTH GOA MINING AREA BASED ON SECTORAL DEMANDS

Table-1: Basin wise Domestic Water Requirements

S.no.	WS-No.	Taluka Name	Total WS Area		Pop. in WS 1991*	Population distribution in the WS, 1991		Annual Water Requirement				Total water requirement per year	
								* Urban @ 0.0073 Ham		* Rural @ 0.0064 Ham			
			Ha	Km^2		Urban	Rural	Ham	Km^3	Ham	Km^3	Ham	Km^3
1	B-1	Bicholim	391	3.91	1348	331	1053	2.42	2.42 $x10^{-5}$	2.12	2.12 $x10^{-5}$	4.54	4.54 $x10^{-5}$
2	B-2	Bicholim	861	8.61	3048	729	2320	5.32	5.32 $x10^{-5}$	4.67	4.67 $x10^{-5}$	9.99	9.99 $x10^{-5}$
3	B-3	Bicholim	1920	19.20	6797	1625	5173	11.86	11.86 $x10^{-5}$	10.40	10.40 $x10^{-5}$	22.26	22.26 $x10^{-5}$
4	B-4	Bicholim	1172	11.72	4149	992	3157	7.24	7.24 $x10^{-5}$	6.35	6.35 $x10^{-5}$	13.59	13.59 $x10^{-5}$
5	B-5	Bicholim	400	4.00	1416	338	1078	2.47	2.47 $x10^{-5}$	2.16	2.16 $x10^{-5}$	4.63	4.63 $x10^{-5}$
6	B-6	Bicholim	3778	37.78	13374	3196	10178	23.33	23.33 $x10^{-5}$	20.45	20.45 $x10^{-5}$	43.78	43.78 $x10^{-5}$
7	S-1	Sattari+ Bicholim	2674	26.74	6070	1141	4929	8.33	8.33 $x10^{-5}$	7.30	7.30 $x10^{-5}$	15.63	15.63 $x10^{-5}$
8	S-2	Sattari	4518	45.18	15994	3823	12171	27.91	27.91 $x10^{-5}$	24.47	24.47 $x10^{-5}$	52.38	52.38 $x10^{-5}$
9	S-3	Bicholim	3034	30.34	10740	2567	8173	18.74	18.74 $x10^{-5}$	16.43	16.43 $x10^{-5}$	35.17	35.17 $x10^{-5}$
10	S-4	Bicholim	661	6.61	2340	559	1781	4.08	4.08 $x10^{-5}$	3.58	3.58 $x10^{-5}$	7.66	7.66 $x10^{-5}$

* As per IS: 1172; 1993, urban water requirement of 200 lpcd and rural requirement of 175 lpcd. Population density is 354 and 100 per km^2 respectively for Bicholim and Sattari. The urban and rural population respectively is 23.9 and 76.1 for Bicholim taluka and 13.7 and 86.3 for Sattari taluka.

Note: WS refers to Water Shed; some watersheds do not strictly confine to the taluka boundaries.

Table-2: Irrigation Water Requirement (mainly for Paddy Cultivation)

S.No.	WS No.	Taluka Name	Area under Agriculture		Av. annual water requirement for Paddy*	Total water requirement per year	
			Ha	Km^2	(m)	Ham	Km^3
1	B-1	Bicholim	107.31	1.0731	0.55	59.02	59.02 $x10^{-5}$
2	B-2	Bicholim	510.94	5.1094	0.55	281.02	281.02 $x10^{-5}$
3	B-3	Bicholim	1081.97	10.8197	0.55	595.08	595.08 $x10^{-5}$
4	B-4	Bicholim	782.10	7.8210	0.55	430.16	430.16 $x10^{-5}$
5	B-5	Bicholim	231.90	2.3190	0.55	127.55	127.55 $x10^{-5}$
6	B-6	Bicholim	1997.44	19.9744	0.55	1098.59	1098.59 $x10^{-5}$
7	S-1	Sattari+Bicholim	1386.81	13.8681	0.55	762.75	762.75 $x10^{-5}$
8	S-2	Sattari	1833.08	18.3308	0.55	1008.19	1008.19 $x10^{-5}$
9	S-3	Bicholim	978.09	9.7809	0.55	537.95	537.95 $x10^{-5}$
10	S-4	Bicholim	256.08	2.5608	0.55	140.84	140.84 $x10^{-5}$

* CGWB and Department of Agriculture, Govt., of Goa, 1997

Table-3: Industrial Water Requirements

S.No.	WS No.	Taluka Name	Industrial Estate Water Requirement	Annual water requirement	
				Ham	Km^3
1	B-1	Bicholim	-	-	-
2	B-2	Bicholim	-	-	-
3	B-3	Bicholim	-	-	-
4	B-4	Bicholim	-	-	-
5	B-5	Bicholim	-	-	-
6	B-6	Bicholim	Bicholim Ind. Est. 250 m^3/day	9	9 $x10^{-5}$
7	S-1	Sattari+Bicholim	-	-	-
8	S-2	Sattari	Honda & Pisssurlem Ind. Est. 1900 m^3/day	69	69 $x10^{-5}$
9	S-3	Bicholim	-	-	-
10	S-4	Bicholim	-	-	-

Source: Goa Industrial Development Corporation, Govt., of Goa

The proposed five industrial Estates in the study area at Bordem, Dhumacam, Latambarcem, Ladphe and Sal together would require 108 Ham of water. This demand is not considered in the present computation.

Table-4: Livestock Water Requirements

S.No.	.WS no.	Taluka Name	Area		Live stock* population as per 1991 census	Annual water requirement @ 30 lpcd is 0.0011 Ham	
			Ha	Km^2		Ham	Km^3
1	B-1	Bicholim	391	3.91	313	0.3443	0.3443 $x10^{-5}$
2	B-2	Bicholim	861	8.61	689	0.7579	0.7579 $x10^{-5}$
3	B-3	Bicholim	1920	19.20	1536	1.6896	1.6896 $x10^{-5}$
4	B-4	Bicholim	1172	11.72	938	1.0318	1.0318 $x10^{-5}$
5	B-5	Bicholim	400	4.00	320	0.3520	0.3520 $x10^{-5}$
6	B-6	Bicholim	3778	37.78	3022	3.3242	3.3242 $x10^{-5}$
7	S-1	Sattari+Bicholim	2674	26.74	1591	1.7501	1.7501 $x10^{-5}$
8	S-2	Sattari	4518	45.18	3614	3.9754	3.9754 $x10^{-5}$
9	S-3	Bicholim	3034	30.34	2427	2.6697	2.6697 $x10^{-5}$
10	S-4	Bicholim	661	6.61	529	0.5819	0.5819 $x10^{-5}$

Note: According to 1991 census the cattle population is 80 and 39 per km^2 respectively in Bicholim and Sattari talukas

Table-5: Water Requirements for Wet Beneficiation and Ore Washing

S.No.	Ws No	Taluka name	Name of beneficiation plant	Annual ore concentrate produced	Annual water requirement @ 0.00014 Ham/tonne of ore concentrate	
				Tones	Ham	Km^3
1	B-1	Bicholim	-	-	-	-
2	B-2	Bicholim	-	-	-	-
3	B-3	Bicholim	-	-	-	-
4	B-4	Bicholim	-	-	-	-
5	B-5	Bicholim	Dempos- Piligao	900'000	126	126×10^{-5}
6	B-6	Bicholim	Dempos-Bicholim	350'000	49	49×10^{-5}
7	S-1	Sattari &Bicholim	-	-	-	-
8	S-2	Sattari	Sesa Goa-Cudnem	1000'000	140	140×10^{-5}
9	S-3	Bicholim	D.B.Bandodkar-Cotambi,Dempos-Surla	320'000	130	130×10^{-5}
10	S-4	Bicholim	Mangali-Navelim,Sesa Goa -Amona	250'000	147	147×10^{-5}

Note: The quantity of water used for beneficiation varies from 1.3 to 1.5 m^3/tone of ore concentrate averaging to about 1.4 m^3/tone of ore concentrate (BRGM Report, 1999, p.32). About 50% of this water come from groundwater via mine pits. 50% of the remaining water is pumped from tidal Mondovi River as seawater is highly flocculating.

Actually 12 to 15 m^3/tone of ore concentrate is the water requirement for wet beneficiation of which 80% is derived from recirculation via tailing ponds. 20% (i.e. 2.7 m^3/tone) is added afresh and 50% of this i.e. 1.35 m^3/tone is derived from groundwater (BRGM Report, 1999, p.33). Therefore in the present computation, groundwater use of @ 0.00014 Ham/tone of ore concentrate is adopted.

Source: TERI, 1997, Area wide Environmental Quality Management (AEQM) plan for the mining belt of Goa. p.304.

Table-6: Groundwater Drafts Through Active Mine Pits

S.No.	WS No.	Taluka name	Ore Production tones per year	Total groundwater draft per year @ 0.0002 Ham / tone of ore	
				Ham	Km^3
1	B-1	Bicholim	1010,000	202	202×10^{-5}
2	B-2	Bicholim	1160,000	232	232×10^{-5}
3	B-3	Bicholim	-	-	-
4	B-4	Bicholim	-	-	-
5	B-5	Bicholim	-	-	-
6	B-6	Bicholim	-	-	-
7	S-1	Sattari + Bicholim	-	-	-
8	S-2	Sattari	3960,000	792	792×10^{-5}
9	S-3	Bicholim	1350,000	270	270×10^{-5}
10	S-4	Bicholim	-	-	-
			Total	4196	4196×10^{-5}

Source: IBM, 2003, TERI, 1997

RAINFALL RECHARGE ESTIMATION FOR THE STUDY AREA

Methodology of recharge estimation for the study area

Using daily sequential water balance model BALSEQ, **Chachadi et al. 2004** has estimated the rainfall recharge values for different land use classes in the mining belt of North Goa. The unit values of aquifer recharge (fraction of rainfall as recharge) derived for each land use class by them has been adopted for the computation of aquifer recharge in the present study area. Therefore by using the estimated area under each land use class and the unit rainfall recharge values, groundwater recharge has been computed for each of the watersheds and is given in **Table-7.** Table 8 shows the groundwater drafts computed using the adopted norms for the mining area in Goa. The status of the groundwater development is also shown in the same table. The total groundwater recharges minus all the withdrawals provide the balance in the aquifer storage. As seen from the table of the 10 mining watersheds 2 are classified as red (> 100% groundwater draft), 1 as black (75-100% groundwater draft), 5 as gray (50 to 75% groundwater draft) and 2 as white (< 50% groundwater draft). This indicates that 7 watersheds are in safe storage and three are critical (B-1, B-2 and B-5). It should be kept in mind that this status is only applicable to shallow lateritic unconfined aquifer in the area under investigation. The deep confined and semi-confined aquifers do not form part of this groundwater balance computation.

II. ESTIMATION OF BASIN WISE GROUNDWATER RECHARGE BASED ON BALSEQ MODEL RESULTS FOR NORTH GOA MINING AREA

Table-7: Computation of groundwater recharge for each of the land use class using watershed area and BALSEQ derived recharge rates for different land use classes

S.No.	Land use Class	BALSEQ recharge (m)	Water shed number and groundwater recharge in Ham									
			B-1	B-2	B-3	B-4	B-5	B-6	S-1	S-2	S-3	S-4
1	Agricultural land	0.54	57.95	275.91	584.26	422.33	124.95	1078.62	748.88	989.86	528.17	138.28
2	Forest land	1.97	-	-	-	-	-	-	1009.70	698.68	-	-
3	Builtup/Industrial/hard surfaces etc	0.69	-	-	46.41	36.62	-	176.05	1.70	9.72	-	-
4	Pastures/grass land /open shrubs	2.08	-	-	-	-	-	1996.53	-	496.91	1299.63	-
5	Barren/fallow/degraded /waste land etc.	1.19	61.64	267.67	249.73	178.75	110.02	490.26	814.25	1884.00	887.72	221.79
6	Mine pits	1.19	61.64	80.84	158.90	-	-	68.75	47.31	214.24	306.58	185.85
7	Barren dumps	0.73	65.27	-	55.31	-	-	-	-		269.63	-
8	Vegetated dumps	1.46	82.72	74.50	50.88	-	-	-	-		-	-
9	Wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Water bodies including mine pits having water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Groundwater Recharge	**Ham**	**-**	329.22	698.92	1145.49	637.70	234.97	3810.21	2621.84	4293.41	3291.73	545.92
	Km^3	**X10^{-5}**	329.22	698.92	1145.49	637.70	234.97	3810.21	2621.84	4293.41	3291.73	545.92

III. ESTIMATION OF BASIN WISE GROUNDWATER DRAFT IN THE MINING AREA OF NORTH GOA

NORMS ADOPTED IN THE PRESENT STUDY: Based on the filed knowledge and information of local conditions the following norms have been adopted for estimation of the groundwater drafts:

1. **Domestic water requirement:** 80% of the total water demand [20% is assumed to come from other than groundwater sources]
2. **Irrigation drafts:** 60% of the total irrigation water requirements [balance 40% of the water requirement is assumed to be met from other than groundwater sources]
3. **Industrial drafts:** 50% of the total water requirements [balance 50% is drawn from other sources]
4. **Livestock drafts:** 50% of the requirements [remaining 50% is used from other than groundwater source]
5. **Wet beneficiation of ores:** 10% of the water added afresh [the details are seen in the Table-5]
6. **Real Evapotranspiration losses from groundwater:** Real evapotranspiration derived from BALSEQ model for Paddy fields, Forestlands and vegetated dumps.
7. **Base flow to rivers, streams and spring flow drafts:** 20% of the groundwater recharge for all land covers
8. **Groundwater drafts through active mine pits:** Actual estimated values.

Table-9: ANNUAL GROUNDWATER BALANCE OF DIFFERENT WATERSHEDS NORTH GOA

S. no.	Groundwater User Catogery	Norms Adopted for GW Withdrawal	Groundwater Drafts (Ham) in different watersheds									
			B-1	B-2	B-3	B-4	B-5	B-6	S-1	S-2	S-3	S-4
1	Domestic water drafts	80% of total demands (Table-1)	3.63	7.99	17.81	10.87	3.70	35.02	12.50	41.90	28.14	6.13
2	Irrigation water drafts	60% of total requirement (Table-2)	35.41	168.61	357.05	258.10	76.59	659.15	457.65	604.91	322.77	84.50
3	Industrial water drafts	50% of total requirement (Table-3)	-	-	-	-	-	4.5	-	34.5	-	-
4	Live stock water drafts	50% of total requirement (Table-4)	0.172	0.379	0.845	0.516	0.176	1.662	0.875	1.988	1.335	0.291
5	Water drafts for wet beneficiation of ores	10% of water added afresh (Table-5)	-	-	-	-	126	49	-	140	130	147
6	Real Evapotranspira-tion losses from groundwater	Paddy field area x 0.382 mts	12.34	21.2	24.70	41.94	1.69	32.53	40.93	43.12	38.16	46.07
		Dense forest cover area x 0.721 mts	-	-	-	-	-	-	369.54	255.71	-	-
		Vegetated mine dump areax0.629 mts	35.64	32.10	21.92	-	-	-	-	-	-	-
7	GW contribution to base flow and spring flows	20% of aquifer recharge derived from BALSEQ model (Table-8)	65.84	139.78	229.10	127.54	46.99	762.04	524.37	858.68	658.35	109.18
8	GW drafts through active mine pits working below WT	Actual computed @ of 2 m^3 / tone of ore mined out (Table-6)	202	232	-	-	-	-	-	792	270	-
9	Total Groundwater Draft in the Watershed (Ham)		355.03	602.06	651.43	438.97	255.09	1543.90	1405.87	2772.81	1448.76	393.17
10	Total groundwater Recharge from BALSEQ model (Ham)		329.22	698.92	1145.49	637.70	234.97	3810.21	2621.84	4293.41	3291.73	545.92
11	Groundwater Balance (Ham)		-25.81	96.81	494.06	198.75	-20.19	2266.31	1215.97	1520.60	1842.97	152.75
12	% Groundwater Utilization in the watershed as on date		107.84	86.14	56.87	68.84	108.56	40.52	53.62	65.00	44.00	72.02
13	Categorization of the Watershed as per CGWB (1984)		Red	Black	Gray	Gray	Red	White	Gray	Gray	White	Gray

Modified groundwater basin classification criteria:

(1) **White** (Non-Critical)- <50%; (2) **Gray** (Sub-Critical)-50-75%; (3) **Black** (Critical)-75-100%; (4) **Red** (Most-Critical)->100% of recharged groundwater is being used presently.

10.Problems identified through the study

The following problems in the mining area under study have been identified:

i) The suspended particulate matter in the mine discharge water, which is used for paddy cultivation, could be a major threat to the sustainability of the fertility of these agricultural lands. Besides, the direct surface runoff from the adjoining mine dumps into the agricultural lands could add to the problem of siltation.

ii) In some of the watersheds the mine pit dewatering has caused depletion in the groundwater levels in the adjoining villages causing water stress conditions. Therefore there is a need to rejuvenate these depleted groundwater reservoirs by some means.

iii) As a short-term solution mining companies are supplying water through their tanker to the problematic villages within their mine jurisdiction. However, the quality of this water needs to be monitored for maintaining the required standards.

11. Some suggested solutions

The most effective way of handling these above problems is through a multi-stakeholder participation approach. The most probable and effective nodal agency which can co-ordinate these works is the **Mineral Foundation of Goa**. In the comprehensive groundwater balance report the problematic watersheds have been identified as red and black categories. Using the mine pit rehabilitation (MPR) methodology (TERI, 2004) the suitable and easily available mine pits should be identified in cooperation with the local mining companies for storage of rainwater to recharge the depleted aquifers. There is a need to check the tanker water quality periodically for any contamination by random sampling of the tanker waters.

The problematic watersheds categorized as water stressed include B1- Sirigao; B2- Mulgao; B5- Piligao; S2- Pissurlem Upper catchment. Immediate attention should have to be paid to these areas for solving the water-related problems.

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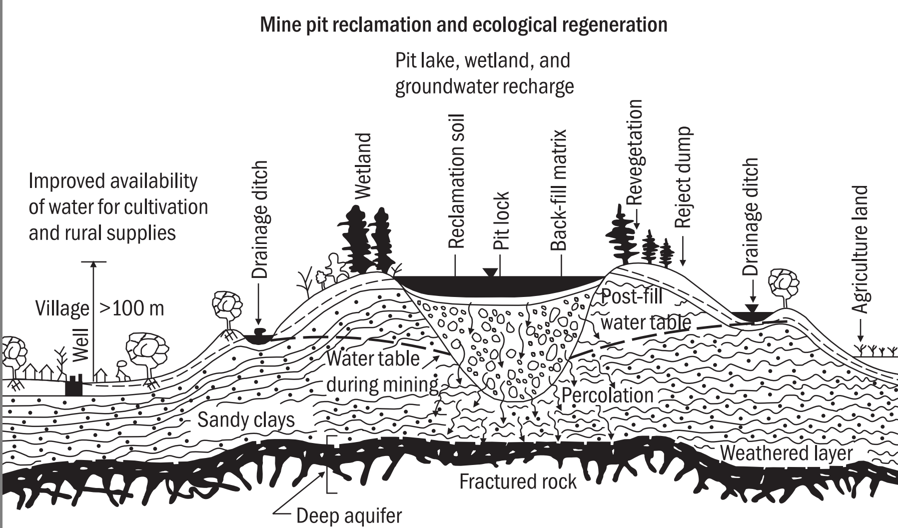
A methodology for evaluation of mine pit rehabilitation using multiple parameter approach



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A decision-making model for mine pit rehabilitation–mine closure plan

Summary

A structured approach based on indicators has been developed as a technical tool to aid the decision-making process of mine pit rehabilitation. The tool is a generic one and can be applied universally. The indicators identified and chosen are based on a combination of field experiences and wide-ranging discussions with experts in the allied fields.

A two-fold decision spectrum, with water storage in the mine pit on one hand and back-filling of the mine pit with rejects on the other, has been adopted while choosing the indicators. Each of these indicators was assigned a weight, and importance ratings for variables based on the Delphi technique (consensus approach). In phase I, the total indicator score derived by summing up the individual indicator scores obtained by multiplication of importance ratings with the corresponding indicator weight is used as a decision-making criterion. The phase I-derived classes related to aquatic use of the pit lake are further subjected to a safety check in phase II using three additional safety indicator parameters. Hence, the two aquatic use classes of phase I get reclassified into three groups as in phase I after a safety check. The end use options of the rehabilitated mine pit either with water or with back-fill have been included as an integral part of the indicators. Table 1 gives a summary of the indicator weights, importance ratings, and the criteria of rating.

Table 1

Summary of indicators weights, importance ratings, and criteria of rating

Indicators details	*Indicator weights*	*Importance rating*		*Criteria used to ascertain the importance ratings*
		Minimum	*Maximum*	
Intensity of water stress in the area where the pit in question is located	2	2.5	10	Status of water availability in the region of interest
Hydraulic conductivity of the mine pit and the surrounding aquifers	2	2.5	10	Water-holding capacity of mine pit and aquifers
Potential uses of pit water	2	2.5	10	Value added to the user community
Constraints of space for mine waste dumping in the buffer zone	2	2.5	10	Availability of space for dumping mine rejects
Composition and nature of back-fill material	2	2.5	10	Toxicity levels of back-fill material
Accessibility of pit lake to users	1	2.5	10	Accessibility levels of pit lake to users
Likely community use of the back-filled and partially back-filled mine pit area	1	2.5	10	Community usage potential of the reclaimed mine pit area

Introduction to mine pit rehabilitation

The mining industry has had a number of positive and significant impacts on the economic development of Goa. Several negative environmental impacts have also occurred, some directly related to the unique features of mining in Goa, and others to the poor mining practices and poor environmental management. Certain difficult conditions are specific to the Goa iron ore mines: international market forces, which determine the iron ore demand and prices, and technical features that effect the mining operations. Some of these include high overburden to ore ratio, combined with the short supply of land, which result in more than the normal height of the reject dumps having steep slopes, below water table working conditions of high potential aquifers, and heavy rainfall conditions adversely influencing the economic costs of operation because of the need for large-scale pit dewatering to provide dry working conditions in the mine pit bottoms. These are a few typical technical features, which overshadow the environmental management practices of the mining companies.

The IBM-BRGM (1999) coordination project on *Regional environmental assessment of the North Goa iron ore mines* has suggested that 'Back-filling projects, properly planned in order to reinstall groundwater and allow future use of pits to access the leftover ore reserves should definitely be considered as a possibility for solving the waste disposal problems'. They have also identified open pit rehabilitation as one of the key environmental problems that needs to be tackled.

Therefore, keeping in mind the above recommendations of the apex organization IBM (Indian Bureau of Mines), the following structured approach has been developed to determine the overall preferences among the alternative options as an aid to the decision-making process of the MPR (mine pit rehabilitation). This approach consists of using a set of indicators that refer to the various conditions necessary for improved decisions.

Problem definition

The research issue that is being addressed here in MPR is based on sound scientific grounds. The decision spectrum of the rehabilitation option assumes water storage in the mine pit at one end and back-filling with mine rejects at the other end.

Background

More than five decades of mining have produced open pits of varying dimensions, some of which have been abandoned due to lack of ore and also due to uneconomic depths of mining. The high ratio of ore to overburden (average 1 : 2.5) combined with land constraints, has recently forced the authorities to go in for back-filling of mined out parts of pits with mine rejects. Back-filling the mine pit with mine rejects without evaluating alternative options that the pit could be used for would amount to a short-sighted approach based only on the need to find space for the mine rejects. This short-sighted approach may not only lead to an ecological imbalance but may also deny the local community of the socio-economic opportunities that these mine pits may create, if used imaginatively. Therefore, it is pertinent at this juncture to look into aspects of the MPR on a holistic basis so that both the local community that has largely borne the brunt of mining and the environment receive their share of benefits of pit rehabilitation.

Objectives

The prime objective of this exercise is to develop a consensus-based decision-making tool for the MPR based on multi-parameter indicators. The indicator tool would provide a simple numerical score to mine managers to decide as to whether to back-fill the mine pit with mine rejects, use it for water storage, or both, so that the maximum post-fill environmental and socio-economic benefits are derived from the rehabilitation exercise.

Methodology

In the present context, two important factors influence the adoption of an indicator-based tool for decision-making.

(a) Level of technical knowledge of the user community to adopt a complex decision-making model.

(b) Availability of data required for adopting any other complex models of decision-making.

Therefore, it is felt necessary to adopt a decision-making tool that is simple to understand and can apply the available data to draw valid and useful conclusions. Adopting an index has the added advantage of in-principle elimination and minimization of subjectivity in the ranking process. An indicator in the present context is a parameter, which influences the decision-making process regarding rehabilitation options of an abandoned/exhausted mine pit for a particular use.

An abandoned mine pit is one where the mining activity has been suspended for the time being due to some reasons despite the lease having the ore reserves. On the other hand, an exhausted mine is one where all ores of the present and future economic importance have been mined out and there is no scope for further mining activity.

The various steps in the evolution of the present indicator tool include the following.

1 *Identification of all indicators influencing the decision-making process* This task was achieved through extensive discussions and consultations with the mine managers, experts, academicians, etc. The final list of relevant indicators was however arrived at by a panel of experts.

2 *Indicator weights* Indicator weights depict the relative importance of the indicator to the decision-making process. After identifying indicators, which can influence the decision-making regarding the MPR, a group of people, comprising geologists, hydrogeologists, environmentalists, students, mining engineers, and in-house experts, were asked to weigh these indicators in the order of importance to the decision process. The feedback was analysed statistically and the final consensus list of indicator weights was prepared. The most significant indicators have weights of 2 and the least have the weight of 1, indicating parameters of less significance in the process of decision-making. As the indicator weights are derived after elaborate discussions and deliberations among experts, academicians, researchers, the local community, and mine managers, they must be considered as constants and may not be changed under normal circumstances.

3 *Assigning of importance rates to indicators using a scale of 2.5 to 10* Each of the indicators is subdivided into variables according to the specified attributes (Table 1) in order to determine the relative significance of the variables in question on the decision-making process. The importance ratings range between 2.5 and 10. A higher importance rating favours water storage while least is for back-filling.

4 *Decision criterion* It is the sum total of the individual indicator scores obtained by multiplication of values of importance ratings with the corresponding indicator weights. Higher the importance of the variable for back-filling, lower is the rate assigned to it, indicating that this would reduce the importance of the water storage options. For example, if the local community could seek a high use of the back-filled mine pit area then the importance rate assigned to this variables is lowest so that its value to decision-making for water storage is minimal, but if the local community is to seek no use of the back-filled mine pit area then the importance rating assigned to this variable is high so that it will let the option in favour of water storage.

An open-ended model: indicator descriptions

The system presented here allows the user to determine a numeric called the MPR index for any hydro-geophysical setting by using an additive model. This model is an open-ended model allowing for addition and deletion of one or more indicators. However, under normal circumstances, the present set of indicators should not be deleted and any addition of the indicator would require re-deriving of the weights and the classification table.

Indicator 1: Intensity of water stress condition in the watershed where the mine pit in question is located

Description

Water stress conditions arise when the quantity of groundwater extracted exceeds the recharge, resulting in an overall severe water shortage in the watershed. Depending upon the magnitude of this imbalance between the total extractions and recharges, the watershed is classified into four categories (modified from CGWB 1984) viz., non-critical (white), sub-critical (gray), critical (black), and most critical (red). No groundwater development activity is allowed in the watersheds in the critical and most critical category areas where groundwater extractions exceed 75% of the mean annual recharge. When the groundwater extractions are less than 50%

of the mean annual recharge, the area is categorized as non-critical and no restriction on groundwater extractions is imposed in such watersheds. In watersheds where the total groundwater extraction balances the mean annual recharge, a cautious approach is adopted in the groundwater development. Therefore, the water stress status of a watershed is an important parameter in the decision-making process regarding mine pit back-filling. In watersheds of most critical and critical categories, it is always preferable if the other conditions favour the use of pits for rainwater storage so that the groundwater regime in the stressed area is rejuvenated over a period of time.

It is usually much wiser to strike a balance between groundwater extraction and availability at a high level of groundwater heads than at a low level (Teresa and Lobo-Ferreira 2002). This is because first, the high levels provide flexibility for temporal overdraft and therefore supply safety. Second, the cost of pumping is lower as the water levels are at shallower depths from the ground. Third, the adverse impacts on groundwater regime are not inflicted, such as seawater intrusion, pollutant mixing, etc. In dry regions, bigger rainstorm events with non-negligible replenishment of groundwater reservoirs may happen rarely and at long time intervals. Sustainable use then means that within this period, a balance between the recharged and extracted volumes must be reached. In those years without effective replenishment, groundwater can be extracted if it is be assumed that till the next recharge event enough water remains in the reservoir to satisfy the basic needs. In other words, in the context of groundwater management, sustainability implies a limitation of extraction rate to a value below the long-term natural replenishment rate. There are, however, additional aspects to sustainability (Kinzelbach and Kunstmann 1999) such as those mentioned below.

- Limitation of groundwater table drawdown to a level, which is compatible with the vegetation needs in the adjoining areas. This is relevant in Goa as many agricultural and horticultural lands are close to dewatering mine pits that drain out the soil moisture to a level whereby the crops/ vegetation start wilting.

- Guarantee of minimum flow rates in downstream drainage basins.
- Prevention of seawater intrusion or salt-water up coning.
- Prevention of long-lasting pollution, land-subsidence, and soil salinization.

Under the natural undeveloped conditions, the groundwater regime is in a dynamic balance with recharges equal to the discharges. However, any anthropogenic activity would change this natural balance between the charges and discharges. Mining is one such activity wherein invariably the groundwater regime is distributed. The groundwater quantity and quality in such areas may get affected at different intensities depending on the magnitude of the activity and intensity of interference into the groundwater regime. Groundwater withdrawals for domestic use and normal agricultural activity may not offset the groundwater balance to significant levels as the recharges balance such small changes under normal rainfall conditions. However, if large-scale activities like dewatering of the mine pit are introduced in the watershed, as in Goa, then it is but natural that the groundwater balance in the watershed is drastically offset. There may be a deficit or surplus groundwater balance depending on the recharge and water use practices in the area.

It is possible to assess a particular watershed for its groundwater balance taking the sum of extractions for water supply, industry, and agriculture, which is divided by the evaluation of recharge. In the present study, the following scheme has been adopted for assessing the groundwater development status in a mining watershed (Table 2). Thus, keeping a mine pit as water buffer storage is rated as most important if the mine pit is located in an area where the availability of water is under stress.

Table 2

Intensity of water stress condition in the watershed where the mine pit in question is located

Indicator	*Weight*	*Indicator variables*	*Importance rating based on status of water availability in the region of interest*
Intensity of water stress condition in the watershed where the mine pit in question is located	2	Non-critical (white): Watershed with groundwater surplus where extraction is less than 50% of the mean annual groundwater recharge	2.5
		Subcritical (gray): Watersheds with ground-water equilibrium where the extractions are between 50% and 75% of the mean annual groundwater recharge	5
		Critical (black): Watersheds groundwater extractions are 75%–100% of the mean annual ground-water recharge. These are stressed watersheds	7.5
		Most critical (red): Most stressed watersheds where groundwater extractions are more than 100% of the mean annual groundwater recharge. Groundwater mining is in operation	10

Data availability

To derive the importance ratings in this case, a detailed groundwater balance status of the watershed in which the mine pit in question is located is required to be worked out. This study normally requires the annual mean groundwater recharge estimation and annual total groundwater drafts by various means. Only an experienced hydrogeologist can do this job. In the present case, such a study has been done for 10 sub-watersheds of the mining areas in North Goa. It has been advised to adopt reliable methods for aquifer recharge estimation such as the BALSEQ model.

Indicator 2: Hydraulic conductivity of mine pit and the surrounding aquifers

Description

Mine pit hydrogeology, the surrounding aquifer properties, and the nature and extent of aquifer(s) play an important role in the decision-making process for water storage in the mine pits. The basic objective of water storage in the pit should be to retain a significant quantity of water in the open pit throughout the year while also allowing a sizable quantity of this pit water to percolate into the surrounding aquifers. This helps in the maintenance of groundwater levels, spring flows, base flow contributions to streams and lakes, besides rejuvenating the depleted groundwater regime after the period of mining. This situation would lead to an overall hydro-ecological regeneration and sustainable water availability in the area. If the hydraulic conditions do not permit to meet the above objectives then the pit water storage may not serve its full purpose. Table 3 provides descriptions of the various hydraulic conditions and the corresponding importance ratings for computing the score of this indicator. Thus, keeping a mine pit as a source of water buffer storage is rated as most important if the pit is located in an area where the availability of water is under stress and the surrounding aquifer is moderate.

Table 3

Hydraulic conductivity of mine pit and the surrounding aquifers

Indicator	*Weight*	*Indicator variables*	*Importance rating based on water-holding capacity of mine pit and aquifers*
Hydraulic conductivity of mine pit and surrounding aquifer	2	Very low conductivity (k = less than 4 m/day)	5
		low conductivity (k = > 4 to < 12 m/day)	7.5
		Medium conductivity (k= > 12 to < 41 m/day)	10
		High conductivity (k = > 41 m/day)	2.5

Note The hydraulic conductivity 'K' values adopted are from DRASTIC model of USEPA (1987).

The last category of the hydrogeological condition having high permeability largely favours groundwater recharge, which otherwise also takes place during the rainy season. The rapid percolation of pit water through the mine pit bottom indicates highly drainable aquifers in the area, which are considered to be unsustainable because these aquifers cannot retain water in them for a long time for use during summer months and therefore this situation is given the lowest rating of 2.5.

Data availability

Permeability of aquifers and the mine pit can be determined by field experiments or by analysis of the aquifer pit bottom material and also by assessing the nature of the rock matrix and rock type. If the rock type and grain sizes are known, one can determine the hydraulic conductivity using relational tables from the standard text books and reports.

Indicator 3: Potential value added from the pit water

Description

Besides the mine pit lake serving the needs of the local water demands, the option of using the pit lake for other economic activities may also be considered in the decision-making. Such socio-economic activities may provide self-employment opportunities leading to better quality life and good health through economic gains. These activities may involve tourism, aquaculture, pisciculture, wetland agriculture, water marketing, etc. In Table 4, the different likely activities are listed along with the relative importance ratings. Thus, keeping a mine pit for water storage is rated as most important if the pit water is used for domestic water supplies with conventional treatment. The importance increases if there are multiple uses of the pit water.

Table 4

Potential uses of pit water

Indicator	*Weight*	*Indicator variables*	*Importance rating based on value addition to the user community*
Potential uses of pit water	2	Domestic water supply with conventional treatment	10
		Propagation of wildlife and fisheries	7.5
		Agriculture use	5
		Industrial use	2.5

Note The indicator variable classification is based on ISI (1982) surface water use standards (IS: 2291)

Data availability

Information about the likely potential uses of the pit water can be ascertained based on the local area water need surveys for various purposes. The type of treatment likely to be given to the pit water can be assessed based on the water quality analysis data of the pit water.

Indicator 4: Constraints of space for mine waste dumping in buffer zone

Description

The constraints of availability of sufficient space for disposal of mine rejects in the buffer zone is an equally important factor as it involves large economic investments. Keeping this aspect in mind, the following indicator options have been identified (Table 5) and importance ratings have been assigned to compute the indicator score. Keeping a mine pit for water storage rather than back-filling is rated as most important if there are no constraints of space dumping for mine rejects in the buffer zone.

Table 5

Constraints of space for mine waste dumping in buffer zone

Indicator	*Weight*	*Indicator variables*	*Importance rating based availability of dumping space in the buffer zone*
Constraints of space for mine waste dumping in the buffer zone	2	High constraints	2.5
		Moderate constraints	5
		Low constraints	7.5
		No constraints	10

Data availability

Information about the suitable space for dumping mine rejects can be gathered from the land survey records from the concerned state departments.

Indicator 5: Composition and nature of back-filling material

Description

Any decision to back-fill the mined pit with a filler material should ensure that the final impact of the back-filled material is not going to affect the intrinsic aquifer properties such as its permeability and storage capacity, and also the groundwater quality. The two most important parameters that need to be considered in this aspect are (i) physical properties of the back-fill matrix, including its grain size, texture, and permeability, and (ii) chemical composition of the matrix as this matrix is likely to come in contact with the percolating water and hence may adversely affect the water quality if the matrix is chemically unstable and contains toxic chemicals. Table 6 provides detailed information on the importance ratings for

Table 6

Composition and nature of back-filling material

Indicator	*Weight*	*Indicator variables*	*Importance rating based on toxicity levels of the back-fill material*
Composition and nature of back-filling material	2	No toxicity	2.5
		Low toxicity	5
		Medium toxicity	7.5
		High toxicity	10

different variables. It is therefore evident that the high toxicity levels of the back-fill material reduce the importance of the back-filling option.

Data availability

The levels of toxicity of the back-fill material can be ascertained by physical and chemical analyses of the material.

Indicator 6: Accessibility of the pit lake to users

Description

The necessity for water storage in the abandoned/exhausted mine pit would arise only if there is an indicated depletion or likely depletion of groundwater and surface water resources in the watershed, and the users need water to meet their various daily demands. Also, if the pit lake water is to be utilized directly then it would have to be located in proximity to the user community or the point of use. Besides, the pit lake should be accessible throughout the year, otherwise direct use would be hindered. Therefore, parameters such as availability of all-season public road networks and proximity of the pit lake to the users should be considered while making a decision regarding the storage of water in the mine pit. Table 7 provides the indicator variables and the corresponding importance rating for computing this indicator score. Thus, keeping a mine pit for water storage is rated as most important if the pit lake is easily accessible and is located close to the potential user groups.

Data availability

Information about accessibility of the proposed pit lake can be ascertained either from the Survey of India topographical maps or from locally available land use, land survey, and village maps.

Table 7

Accessibility of the pit lake to users

Indicator	*Weight*	*Indicator variables*	*Importance rating based on accessibility levels*
Accessibility of the pit lake to users	1	Most accessible	10
		Moderately accessible	7.5
		Can be made accessible	5
		Inaccessible	2.5

Indicator 7: Likely community use of back-filled and partially back-filled mine pit area

Description

It is not difficult to assess the rehabilitation options or likely uses of the back-filled mine pit area based on the local requirements of the community and the prevailing potential activities. Under this indicator, several end use options can be identified and classified into different categories (Table 8). Thus back-filling mine pit rather than keeping it for water storage is rated more important if the back-filled mine pit area has a high potential for different community uses such as agriculture, horticulture, pasture land development, forestry, waste disposal, sports, etc.

Data availability

The likely potential uses of back-filled mine pit area can be ascertained by knowing the purpose and needs of the local community, besides the suitability and structural stability of the back-filled area for specific use. This can be achieved by active participation of the local community.

Table 8

Likely community uses of back-filled and partially back-filled mine pit area

Indicator	*Weight*	*Indicator variables*	*Importance ratings based on community use potential of the back-filled mine pit area*
Likely community uses of back-filled and partially back-filled mine pit area	1	High potential for use	2.5
		Medium potential for use	5
		Low potential for use	7.5
		No potential for use	10

Computing of mine pit rehabilitation index

Each of the seven indicators has a pre-determined fixed weight, which reflects its relative importance to rehabilitation decision-making. The MPR index is then obtained by computing the individual indicator scores and summing them as per the following expression (Equation 1).

$$\text{MPR index} = \sum_{i=1}^{7} [(W_i)R_i] / \sum_{i=1}^{7} W_i \quad \ldots (1)$$

Where, W_i is the weight of the i^{th} indicator and R_i is the importance rating of the i^{th} indicator.

Thus, the user can use hydrogeologic, topographic, demographic, land use, mine pit settings, etc. from the area of interest, choose variables to reflect the specific conditions within that area, choose the corresponding ratings, and compute the indicator score. This system allows the user to determine a numerical value for any hydro-geographical setting by using this additive model. The 'maximum MPR index' is obtained by substituting the maximum importance ratings of the indicators as shown in Equation 2.

$$\text{Maximum} =$$

$$[2\times R_1 + 2\times R_2 + 2\times R_3 + 2\times R_4 + 2\times R_5 + 1\times R_6 + 1\times R_7] / \sum_{i=1}^{7} W_i$$

$$[2\times 10 + 2\times 10 + 2\times 10 + 2\times 10 + 2\times 10 + 1\times 10 + 1\times 10]/12 = 10 \quad \ldots (2)$$

Similarly, the ‘minimum MPR index’ is obtained by substituting the minimum importance ratings of the indicators as shown in Equation 3.

Minimum =

$$[2\times R_1+2\times R_2+2\times R_3+2\times R_4+2\times R_5+1\times R_6+1\times R_7]/\sum_{i=1}^{7} W_i$$

$$[2\times 2.5+2\times 2.5+2\times 2.5+2\times 2.5+2\times 2.5+1\times 2.5+1\times 2.5]/12 = 2.5 \quad \ldots (3)$$

Therefore, the minimum and maximum MPR index vary between 2.5 to 10. The feasibility of a particular mine pit for a specific rehabilitation purpose is assessed based on the magnitude of the MPR index. In a general way, higher the MPR index, better the feasibility for using the pit for water storage. Likewise, the lower values of MPR index emphasize for back-filling of pits with mine rejects. The intermediate values dictate a combination of both options of back-filling and water storage in pits.

Decision criteria

Phase I

In phase I, once the MPR index has been computed, it is possible to classify the individual mine pits into various categories for taking appropriate rehabilitation measures. The range of minimum and maximum MPR index score (that is, 2.5 to 10) is divided into three groups as shown in Appendix 1. All the seven indicators have 2.5, 5, 7.5, and 10 as their importance ratings. Table 9 and Figure 1 provide the detailed classification as derived from Appendix 1.

Table 9

Rehabilitation decision table using MPR (mine pit rehabilitation) index: phase I

MPR index	*Rehabilitation classification*
> 7.5	Mine pit should be used exclusively for water storage
5 to <7.5[a]	Mine pit should be partially back-filled with mine rejects with the provision for water storage on the top portion
< 5	Mine pint should be used exclusively for back-filling with mine rejects

[a] the technical committee may decide the level of back-filling in this category

Note of caution

This model is not an absolute answer for decision-making, especially when the model score points to the middle option because some indicators would be overshadowing the other important indicators. For example, if the MPR index indicates the middle option but the indicator 'composition and nature of the back-fill material' is showing very high score (that is, the back-fill material is unsuitable for back-filling) then in such situations, caution should be exercized in back-filling with material of low chemical quality, which may badly affect the groundwater regime in the neighbouring area. Therefore, besides using the model score, the decision-maker should exercise wisdom and make use of the local area experience while making the final decision.

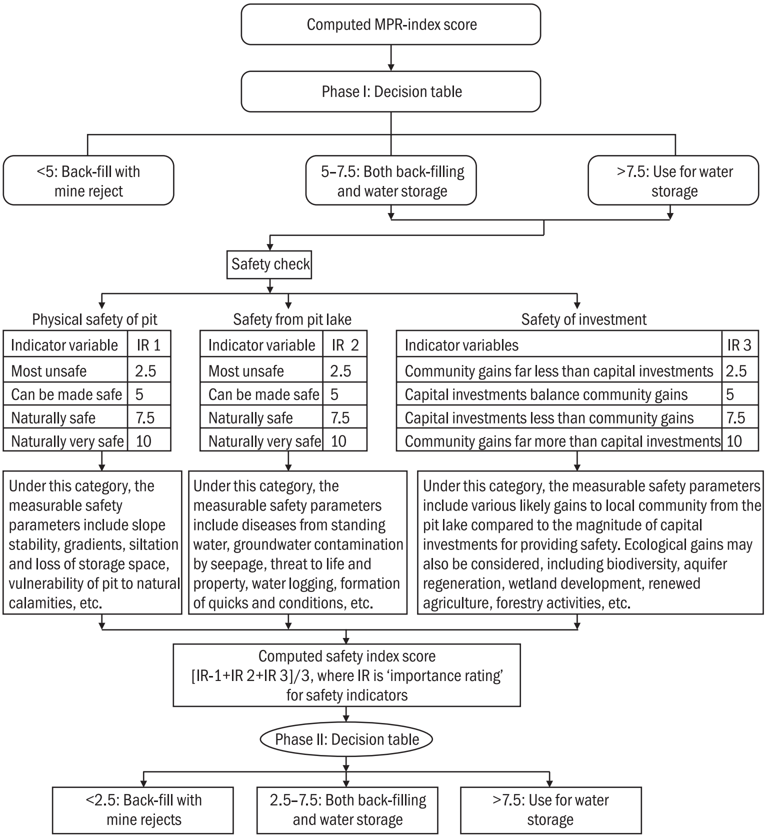

Figure 1

Decision-making flow chart regarding MPR (mine pit rehabilitation)

Phase II

Once water is stored in the abandoned/exhausted mine pit, it will form a pit lake of a significant size. As such many pits are located on the elevated landforms (hill ridges) and hence there can be a number of safety problems arising from the pit lakes. Safety of humans, cattle, wildlife, and the natural environment should therefore be taken into account while deciding on the storage of large quantities of water in the mine pits. The possible dangers of breaching of the mine pit lakes during earthquakes and other natural calamities must also be considered. The pits when filled with water should meet all the safety requirements.

The classification options of a mine pit for use, as fully for water storage and also partial water storage, have safety consequences. Therefore, these two classes should fulfil the safety requirements. In phase II of the classification, these two options have been subjected to safety checks. In order to achieve this, two safety checks criteria are evolved: first, dealing with the physical safety of the mine pit itself, involving slope stability, ground gradients, potential for siltation, vulnerability to natural calamities, etc. and second, dealing with safety aspects arising from the impounded water in the mine pit itself. This involves parameters of outbreak of waterborne diseases, groundwater contaminations through seeping pit water of poor quality, threat to life and property, water logging of potential agricultural and settlement areas, quicksand formations, etc. The third safety parameter is related to capital investment towards making the pit lake safe. However, this third safety check is evaluated in relation to community gains arising from the presence of the pit lake.

The range of minimum and maximum safety-index scores (that is, 2.5 to 10) is divided into three groups (Appendix 2). All the three safety indicators have 2.5, 5, 7.5, and 10 as their importance ratings. Figure 1 provides full details of the decision process.

Demonstration of the model using actual field example

Example I

A working iron ore mine is located in the Kudne village (S2 watershed) and has a length of about 1000 m and width of about 500 m. Presently, mine rejects are transported to a nearby locality. In order to demonstrate the application of the present model, this pit has been chosen because all the required data of the indicators was available. Importance ratings of the indicators derived for the pit are listed and the total indicator score of 5.63 has been computed (Table 10). Using this MPR index and the classification (Table 9), the rehabilitation option for this mine would be 'both combination of partial back-filling and water storage'. The safety check (Table 11), which provides a safety score of 7.5, also indicates the same rehabilitation option.

Table 10

Example of rehabilitation decision of Kudne mine using indicator model; phase I

Indicator details	*Indicator weights*	*Importance rating for Kudne pit*	*Indicator score*
Intensity of water stress in the area where the pit in question is located	2	5	10
Hydraulic conductivity of the mine pit and the surrounding aquifers	2	5	10

Continued...

Potential uses of pit water	2	10	20
Constraints of space for mine waste dumping in the buffer zone	2	5	10
Composition and nature of back-fill material	2	2.5	5
Accessibility of pit lake to users	1	10	10
Likely community use of the back-filled and partially back-filled mine pit area	1	2.5	2.5
Total indicator score			**67.5**
MPR (mine pit rehabilitation) index 67.5/12			**5.63**

Table 11

Safety check for Kudne mine; phase II

Indicator details	*Indicator weights*	*Importance rating for Kudne pit*	*Indicator score*
Physical safety of the pit	3	7.5	22
Safety from the pit lake	3	5	15
Safety of investment	3	10	30
TSS (total safety score)			**67.5**
Safety index = TSS/9 (that is, 67.5/9)			**7.5**

Example II

A group of working iron ore mines located in S2 watershed near Pissurlem village has a combined area of about 1 km^2. Presently, the mine rejects are transported to a nearby locality. It has been proposed to find out about the rehabilitation of these mine pits after they cease in their operation. In Table 12, the importance ratings of indicators derived for the pits are listed and the total indicator score of 5.63 has been computed. Using this MPR index value and the classification in Table 9, the rehabilitation option for this mine would be ‘for combination of both back-filling with the mine reject and water storage’. The safety check (Table 13), which provides a safety score of 5, also indicates the same rehabilitation option.

Table 12

Example of rehabilitation decision of Pissurlem mines using MPR (mine pit rehabilitation) index

Indicator details	*Indicator weights*	*Importance rating for Kudne pit*	*Indicator score*
Intensity of water stress in the area where the pit in question is located	2	10	20
Hydraulic conductivity of the mine pit and the surrounding aquifers	2	5	10
Potential uses of pit water	2	10	20
Constraints of space for mine waste dumping in the buffer zone	2	2.5	5
Composition and nature of back-fill material	2	2.5	5
Accessibility of pit lake to users	1	5	5
Likely community use of the back-filled and partially back-filled mine pit area	1	2.5	2.5
Total indicator score			**67.5**
MPR index 67.5/12			**5.63**

Table 13

Safety check for Pissurlem mines; phase II

Indicator details	*Indicator weights*	*Importance rating for Kudne pit*	*Indicator score*
Physical safety of the pit	3	5	15
Safety from the pit lake	3	5	15
Safety of investment	3	5	15
TSS (total safety score)			**45**
Safety index = TSS/9 (that is, 45/9)			**5**

Note The above examples may require refining of data; groundwater development has been assumed to be most critical in this case.

Conclusions and recommendations

The MPR index tool has been developed keeping in mind the technical limitations of the mining community to make best use of this model for decision-making. The indicator variables have been described in a nutshell for ease of reference. However, there is scope for choosing the indicator variables and hence the importance ratings in a biased manner to suit the requirements. Therefore, in order to avoid such biased decision-making, it is highly recommended to constitute the TAC (technical advisory committee) for mine pit rehabilitation, representing the following.

1. An hydro-geologist of repute who is well-versed with the local groundwater status
2. A chemist who may be from a research and academic institution having insight into the toxicological impacts of chemicals on the environment
3. An environmental/mining engineer from the mining company
4. District collector of the respective district
5. A representative of the Indian Bureau of Mines
6. A representative of the local community/local NGO
7. A representative of the department of rural development.

The IBM can work out the terms of reference of the above committee. All necessary technical and other data of the model should be made available to the committee before they meet to decide on the options. Besides, the concerned mining company has to workout the MPR index and put it up to the TAC for final approval before taking any action on the matter.

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Appendix 1

Computation of MPR (mine pit rehabilitation) index: phase I evaluation

Indicator	Weight	*Range of importance ratings*				*Range of scores (weight importance rating)*			
		Minimum	*In-between*		*Maximum*	*Minimum*	*In-between*		*Maximum*
Intensity of water stress in the area where the pit in question is located	2	2.5	5	7.5	10	5	10	15	20
Hydraulic conductivity of the mine pit and surrounding aquifers	2	2.5	5	7.5	10	5	10	15	20
Potential value added from the pit water	2	2.5	5	7.5	10	5	10	15	20
Constraints of space for mine waste dumping in the buffer zone	2	2.5	5	7.5	10	5	10	15	20
Composition and nature of back-fill material	2	2.5	5	7.5	10	5	10	15	20
Accessibility of pit lake to users	1	2.5	5	7.5	10	2.5	5	7.5	10
Likely community use of the back-filled and partially back-filled mine pit area	1	2.5	5	7.5	10	2.5	5	7.5	10
TS (total score)	**30**	**60**	**90**	**120**					
MPR index = TS/12	**2.5**	**5**	**7.5**	**10**					

Appendix 2

Computation of safety-index: phase II evaluation

		Range of importance ratings				*Range of scores (weight importance rating)*			
Indicator detail	*Weight*	*Minimum*	*In-between*		*Maximum*	*Minimum*	*In-between*		*Maximum*
Physical safety of the pit	3	2.5	5	7.5	10	5	10	15	20
Safety from the pit lake	3	2.5	5	7.5	10	5	10	15	20
Safety of investment	3	2.5	5	7.5	10	5	10	15	20
TSS (total safety score)	**30**	**60**	**90**	**120**					
Safety index=TSS/9	**2.5**	**5**	**7.5**	**10**					

Pilot-scale trials of plantation and soil–water conservation measures on representative mine dumps:

a case study from North Goa

DFID Department for International Development

The Energy and Resources Institute teri

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For more details, please contact

Dr B S Choudri
TERI (The Energy and Resources Institute)
Policy Analysis Division
Western Regional Centre
F-9, La Marvel Colony
Entry No. 3
Dona-Paula – 403 004
Goa State
India

Tel. 91 832 245 6053
Fax 91 832 245 6053
Mobile 91 (0) 9422059270
E-mail bchoudri@teri.res.in
Web www.teriin.org/teri-wr

Introduction

The impact of mining on land, air, and water has been debated for quite some time. The present intense mining activity at the expense of the environment has resulted in a global awareness towards undertaking studies for providing the means to counter the environmental damage.

In Goa, indiscriminate mining has resulted in profound ecological degradation. Mines and their dumps are situated on hillocks. As a result, during heavy monsoon, huge quantities of silt material from the dumps wash away and deposit in the nearby agricultural field, watercourses, and private and public lands located at lower levels, thus contributing to degradation of these resources.

The pilot-scale trails of plantation on the representative degraded lands are well conceived, and planned experiments have been carried out. These advanced techniques of rehabilitation would help in controlling further degradation of the resources. Techniques have been developed looking at the existing dump material in Goa, and three models of rehabilitation have been implemented, which resulted in an improvement in the physico-chemical properties of soil, reduction in soil erosion, improvement in water conservation, and green coverage of the area. Details of these models of rehabilitation and their application in the Goa case study are discussed.

Mining in Goa generates huge amounts of rejects. In order to mine a tonne of ore, two-to-three tonnes of rejects are removed, resulting in about 30 million tonnes of rejects being generated annually (ore-to-ore burden ratio ranges from 1 : 2.5 to 3 tonnes). These dumps are partially rehabilitated with unscientific methods, and hence, the dump material flows into fertile agricultural lands and streams (*nallahs*) as well as into the working mine pits. Mine rejects are disturbed ecosystems and

Unsuccessful plantation on dumps without treatment are most often physically, chemically, biologically, and nutritionally poor media for plant growth. Acidity, poor water-holding capacity, and other adversities to soil are some of the major problems in rehabilitating the mine dumps. Soil amendments, mulching, and topsoil replacement are practices that usually result in favourable conditions for plant growth. Selection of plant species with suitable ecological traits in order to speed up the process of regeneration is critical. Long-term maintenance and monitoring are also essential.

Background

Pilot-scale trials of plantations on degraded lands are part of a larger project that TERI is engaged in, titled *Planning for sustainable regeneration in mining areas using tri-sector partnerships.* This project is a logical extension of the research underway within TERI towards promoting sustainable development in the minerals industry of Goa.

This trial was a technical component with the following objectives.

- Development of a method for rehabilitation of abandoned mine dumps.
- Identification of suitable amendments, plant species for initiating the process of ecological succession.
- Development of tri-sector partnerships amongst mine owners, the community, and the government for sustainable management of the rehabilitated abandoned mine dumps.

Study area

For the pilot experiment, a small piece of representative mine-degraded land was selected at Dempo Mining Co. old dumpsite at Dhabadaba mining operations near Bicholim, North Goa (approximate latitudes of 15^0 34′ 45″ to 15^0 35′ 20″ N and longitudes of 73^0 55′ 0″ to 73^0 56′ 15″ E), for the proposed experiment. The area of the dump is about 20 ha (hectares). Two-third of the dump area is pitched with laterite stones to stop sediment movement. About one-third is not pitched and has barren slopes, varying at 15^o–45^o (average). Rainfall is about 2800–3700 mm. Monsoon starts in mid-June. Maximum temperature is 35–37 ^{o}C and drops by about 5–6 ^{o}C after the onset of monsoon.

Methodology

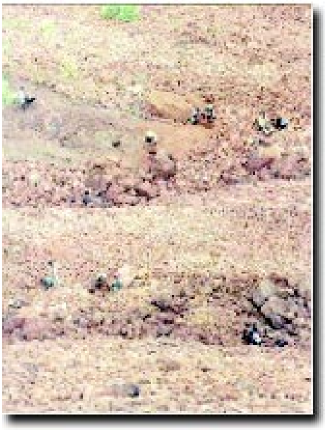
- A 5-ha area of the dumps has been selected for the trial plot. The substrate has been analysed for nutrient deficiencies, in terms of requirements of the selected species, and necessary inputs have been given to ameliorate it into a medium well-suited for growth and development of the vegetation.
- Screening of the species of trees, shrubs, grasses, and legumes was done with special consideration to the edaphological condition of the substrates, their establishment capability, nutrient-extraction efficiency, and growth.
- Site preparation was done before the onset of monsoons, and the plantation was carried out following the standard method. In addition to trees and shrubs, suitable grasses and legumes were sown to cover the surface not only to conserve soil and water, but also to enrich the medium with organic matter, and augment the availability and circulation of nutrient elements in plants.

Quality of dump material

The first step was the collection and analysis of the dump material. About 10 samples were collected randomly in 5 ha of the rehabilitation area. These samples were analysed for quality of the dump material using standard methods. Results showed that the dump material was acidic in nature, and lacked essential nutrients (in terms of nitrate and phosphate) and soil conditioning.

Site preparation based on three models

Stone pitched area The 2.5 ha of the pitched area was treated fully for soil conservation and planning for planting of grass/tree/bush species was done. The slope of this dump was 30°–40° (Model A). Stone pitching is a type of practice to reduce soil/dump erosion. Stones are pitched closely over the entire dump material/heap and they conserve moisture in the lean season and completely arrest the down flow.



View of Model A

Inward bench terracing In 1.5 ha, the slope was reduced to about 10° or below with the help of inward bench terraces. Bench terracing (Model B) involves converting the original huge dump material into levelled step-like fields constructed by half-cutting and half-filling. This helps in considerably reducing the degree of slope. In addition, it also helps in the uniform distribution of soil moisture, retention of soil and manure, and is best for irrigation water, all of which together add to productivity of the land. The advantage of inward sloping of bench terraces is that it is suitable for high rainfall areas with deep permeable soil, and bench terraces reduce the runoff by 50% and soil loss by 98%.

View of Model B

Using gunny bag crates In 1 ha, the slope is tackled with the help of installation of gunny bag crates along the slope of the dump material following the contours (Model C). This is a method of placing gunny bag crates in a staggered manner all along the slope of the dumps at different levels. Gunny bag crates are filled with the dump material and tied with a woven GI (galvanized) wire.

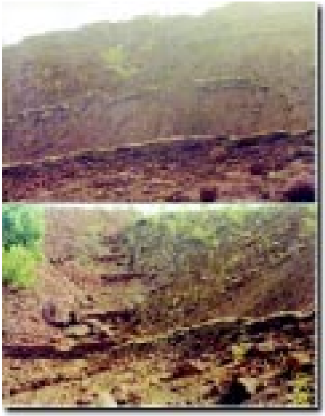
View of Model B

Table 1 gives details on the three models of rehabilitation and the area covered by them.

Table 1 Models of rehabilitation

Name of area	*Model name*	*Area* (in hectares)
Stone-pitched area	A	2.5
Bench-terraced area	B	1.5
Soil-eroded area or gunny crates area	C	1.0
Total		5.0

Pit digging for tree/grass species



View of Model C

- Pits of the size of 45 × 45 × 45 cm were dug at a spacing of 3 × 3 m.
- About 1000 pits were dug per ha area, totalling to about 5000 pits in 5 ha.
- About 2500 pits were dug by opening stones in the 2.5 ha of the stone-pitched area (Model A) and gaps were covered with the help of broadcasting grass and bush seeds before the onset of the monsoon. About 1650 and 1025 pits were dug in Model B and Model C, respectively.
- About 2500 grass pits were prepared in the size of 2 × 2 × 0.10 m for planting of grass species in between the tree species. It was carried out on unpitched surface or barren surface for the grass seed sowing and plantation of rhizomes.

Table 2 gives the model-wise pits and soil–water conservation measures.

Amendments

These results showed that the dump material is acidic in nature and lacking in essential nutrients as well as in soil conditioning. Amendments such as farmyard manure, gypsum, and mycorrhizae were selected and used based on the results of the quality of the dump material. The details of the quantity of amendments used are given in Table 3 and summarized below.

- About 60 tonnes of farm yard manure was used at the rate of 6 kg for tree species and about 14 kg for grass species.
- About 80 tonnes of lime (gypsum) was used at the rate of 8 kg for the pits of tree species and 18 kg for pits of grass species.
- Also mycorrhiza was used, which was applied in a powder form. The 20-kg powder containing mycorrhiza was mixed with fine 40 kg of farmyard manure for 5 ha of area.

Table 2 Model-wise pits and soil–water conservation measures

Name of intervention	*Model* A	*Model* B	*Model* C	*Total*
Site preparation				
Bench terracing (number)	—	5	4	9
Bunding (hectares)	—	0.6	0.4	1
Soil and water conservation				
Pit digging 45 × 45 × 45 m size (number)	2350	1625	1025	5000
Seed pits 2 × 2 × 10 m size (number/hectares)	—	1500/0.6	1000/0.4	2500/1.0
Gully plugging (number)				
Minor size	—	9	50	59
Major size	—	—	8	8
Total	—	9	58	67
Gunny bag toe-wall (number)	—	—	4	4
Gunny bag crates (3 × 6 × 6 m size) (number)	—	—	70	70
Water harvesting or percolation ponds (number)	1	2	—	3

Table 3 Ratio of amendments applied for dumps/soil treatment

Name of amendment	*Size of pits* 0.45 × 0.45 × 0.45 metres	*Size of pits* 2 × 2 × 0.10 metres	*Size of pits* Others (back of gunny bag crates)
Cow dung	6 (kg per pit)	14 (kg per pit)	2 (kg per crate)
Gypsum	8 (kg per pit)	18 (kg per pit)	5 (kg per crate)
Mycorrhiza	20 kg for the entire rehabilitation area in ratio of 1 : 2 : 3 (that is, mycorrhiza + cow dung + water)		

Species used in each model of rehabilitation

Method of applying mycorrhiza

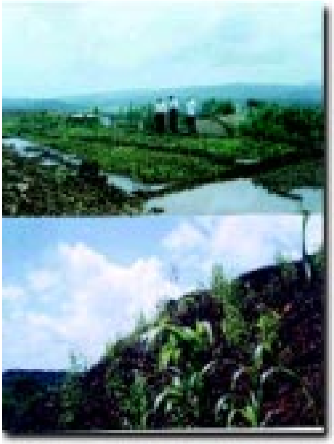
In each model of rehabilitation, plant species, grasses, and bushes have been used towards the soil- and water-conservation measures.

- In the stone-pitched area, that is, Model A, the total number of plant species used (in combination) is 2350. These plants are *Anacardium occidental (grafted + seedling), Garcinia indica, Emblica officinalis, Dendrocalmus strictus, Alastonia scholaris, Acacia auriculiformis, Acacia mangium, and Casurina equisitifolia*.
- In Model B (inward bench-terraced area), the total number of plant species used are about 1625. These plants are *A. occidental (grafted), G. indica, and E. officinalis.* All these species are planted in combination all along the five bench terraces. There are six varieties of bush species being planted in combination, such as *Panicum maximum*, *pinnisetum pendicellatum*, *Dadonea viscose*, *vetiver zizanoides, Stylosanthes guianensis,* and *panincum antidolta.*
- In Model C (gunny bag crates area), the total number of plant species, planted in combination, is about 1025. The main plant species are *A. occidental* (grafted + seedling), *Dedrocalamus strictus*, *G. indica*, and *A. auriculiformis*. About 1000 species of *Agave America* are planted in the backside and frontside of the gunny bag crates and 4 kg seeds of *P. pedicellatum* are also used all along the slopes.

View of well-grown plant species

Stylo-haemata grass on the benches

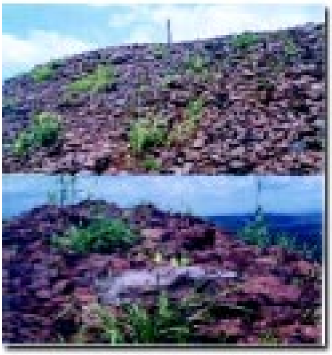
Observed changes in the dump material after treatment



Growth of plant species

Changes have been observed in the quality of the dump material after treatment by use of amendments. Before treatment, the dump material was acidic in nature and lacked in essential nutrients. After treatment with necessary amendments, the dump material changed in its quality from acidic to basic. It was also noticed that the contents of phosphate and nitrates increased and the per cent iron content reduced. In other words, the dump material showed good enrichment of essential nutrients, which further helped in better growth of the experimented species.

Status of growth of species



Grass grown in the stone-pitched area

The planted species of trees and grasses have shown a substantial growth, which has been observed through the monitoring activity from quarter to quarter. Tree species have grown very well in the terraced area and gunny bag crates area in comparison with the stone-pitched area of rehabilitation. Species of grasses in each model show a very good media for arresting the downflow of the dump material. Overall, the species in all the models indicated a luxurious growth with respect to time and change in climatic conditions within the area, and the mortality rate is less (about 10%).

Status of different types of soil- and water-conservation measures

In this rehabilitation process, many techniques have been used for on site soil- and water-conservation measures as part of a scientific approach in each model. The technique of inward bench terracing (most beneficial in reducing the slopes of dumps) has been most useful as an efficient means of soil-conservation through arresting siltation as well as maintaining soil moisture for substantial growth of the planted species and enrichment of essential nutrients. Besides inward bench terracing, adoption of counter bunding technique and rainwater-harvesting structures are also useful and economical techniques for improved and successful rehabilitation.

It has already been mentioned that gunny bag crates have been placed with help of the GI wire in the high slope area (slope of 40°–50°). This technique of placing gunny bag crates (in a staggered manner) along the slopes has shown very good results and almost all these bags are undisturbed and most successful in stabilizing the down flow of the dump material. These structures also give a very good boost to the grass and tree species to grow in a better way by supplying the soil with moisture and protecting it from erosion. Other structures adopted along the slopes, such as construction of loose boulder checks using the local laterite stones along the gullies and on the upper reaches of gully plugging, have further helped to control the complete erosion process. Table 4 gives the cost involvement on each item of rehabilitation.

Estimated cost for selective type of rehabilitation

From the experiment, it is noticed that rehabilitation in the stone-pitched area would cost less than 50 000 rupees per ha (excluding stone pitching cost, which is high). Rehabilitation with the help of inward bench terracing would cost 115 000 rupees per ha and is found to be a very effective method of rehabilitation. Rehabilitation with gunny bag crates would cost 130 000 rupees per ha (Table 5) and it is the most effective technique in the areas of dumps having a steep slope.

Experience gained in rehabilitation work

To reduce the labour component and ensure best results of rehabilitation work, the following points would be beneficial.

- Favourable time slots for working
  - October–December: soil and water conservation work
  - January–February: advance soil working
  - April–May: good time for mixing and filling pits sowing

Table 4 Breakdown of costs for each of the three options of rehabilitation (models A, B, and C)

Item	*Assumptions and details*	*Cost* (rupees)[a]		
		Model A	*Model B*	*Model C*
Digging pits for saplings	2350 pits over 2.5 ha for A; 1625 pits over 1.5 ha for B; 1025 pits over 1 ha for C	7 5000	5 2000	3 300
Digging pits for sowing grass	1500 pits for B; 1000 pits for C	—	21 000	14 000
Installing staggered crates of gunny bags	Installing a 4-toe wall for C	—	—	16 000
Plugging gullies	At 9 points for B; at 58 points for C	—	700	4 400
Building water-harvesting structures	1 structure for A; 2 structures for B	1 100	10 700	—
Heaping cowdung next to each pit	2350 pits for A; 1625 + 1000 pits for grass for B; 1025 + 1000 pits for grass for C	3 000	3 400	3 800
Unloading 80 tonnes of gypsum		3 200	3 200	3 200
Heaping gypsum next to each pit		3 000	4 000	4 800
Mixing the cowdung and gypsum with soil and filling the pits with this mixture		3 500	4 700	4 500
Sowing grass on soil beds		10 000	10 000	10 000
Planting the saplings (includes dipping them in mycorrhiza solution and staking to support each sapling)		3 000	2 000	2 500
Weeding, mulching, and irrigation		20 000	20 000	20 000
Water supply by a tanker	3 trips a week; 350 rupees per trip	1 050	1 050	1 050

[a] rounded off to the nearest hundred

Table 5 Estimated approximate cost for each type of rehabilitation	
Type of rehabilitation	*Estimated cost* (rupees per ha)
Rehabilitation in stone-pitched area	50 000
Rehabilitation by inward terracing	115 000
Rehabilitation with gunny bag crates	130 000

- End of May: planting
- September: hoeing and mulching

- To retain soil moisture, partial water, and for soil conservation, water-harvesting structures like percolation ponds are essential on the rehabilitation dumps. They should be constructed at suitable places as per the needs and requirements.
- Maintenance in the second year is necessary so that all damaged structures are repaired and dead plants are replaced.
- Timely hoeing, mulching, watching, and warding is needed.


View of bajra grown on dumps

Recommendations

- A treatment map should be prepared after survey of the mine dump area, which is to be rehabilitated. The type of soil- and water-conservation measures, number of pits for plantation, and space for grass/legumes must be depicted on the map.
- The physico-chemical properties of the soil dumps must be analysed. The quantity of amendments should be calculated on the basis of the physico-chemical properties of the soil samples of the rehabilitation area.
- Inward bench terracing is recommended for slopes less than 35^o, gunny bag crates are recommended for areas having slopes more than 35^o. Gully plugging is also needed where big cracks are seen along the slopes.

- Stone pitching is recommended in those mine dump areas where water sources are affected due to heavy erosion. It is the most expensive soil- and water-conservation method, which may not be recommended for adoption on a large scale.
- It is advisable to construct the toe wall at the low end of the area to check the erosion downwards.
- It is advisable to complete the earth working and mixing of amendments by March-end. The area then should be left for weathering. Pits of 45 × 45 × 45 cm size at the space of 3 × 3 m for tree species and working of soil till 10 cm deep is recommended for grass/legume species.

Well-grown dinanth grass on dump

- Gypsum and organic manure is recommended to improve the physico-chemical condition of soil. The use of mycorrhiza will also help the vegetation in stress conditions. The quantity will be decided on the basis of the physico-chemical properties of soil of the mine dumps.
- It is advisable to complete the planting of trees as well as grasses/legume species before the onset of the monsoon, that is, by May-end under artificial irrigation. The silvipastoral model of plantation is recommended for rehabilitation.
- Cashew, *A. auricauliformis*, *A. mangium*, kokum, and aonla tree species are recommended plantations for rehabilitation.
- Planting of agave is also recommended behind the gunny bag crates.
- *P. pedicellatum*, *Dedonea viscose,* and *Stylosanthes guinanensis* are recommended for coverage of the ground flora.
- Mulching and artificial irrigation is recommended from November–April. The grasses/legumes are cut on a regular basis and converted into organic manure. It is advisable to use them in the rehabilitation area for three years.
- The broken soil- and water-conservation structures have been recommended to be repaired before the next monsoon. Care of the rehabilitation area is recommended for a minimum of three years and then it is advisable to transfer it to the community and mine owners for further management and benefit sharing.

Information board at the site

About TERI

A dynamic and flexible organization with a global vision and a local focus, TERI was established in 1974.

While in the initial period the focus was mainly on documentation and information dissemination, research activities in the fields of energy, environment, and sustainable development were initiated towards the end of 1982. The genesis of these activities lay in TERI's firm belief that efficient utilization of energy, sustainable use of natural resources, large-scale adoption of renewable energy technologies, and reduction of all forms of waste would move the process of development towards the goal of sustainability.

A unique developing-country institution, TERI is deeply committed to every aspect of sustainable development. From providing environment-friendly solutions to rural energy problems to helping shape the development of the Indian oil and gas sector; from tackling global climate change issues across many continents to enhancing forest conservation efforts among local communities; from advancing solutions to growing urban transport and air pollution problems to promoting energy efficiency in the Indian industry, the emphasis has always been on finding innovative solutions to make the world a better place to live in. However, while TERI's vision is global, its roots are firmly entrenched in Indian soil. All activities in TERI move from formulating local- and national-level strategies to suggesting global solutions to critical energy and environment-related issues. It is with this purpose that TERI has established regional centres in Bangalore, Goa, Guwahati, and Kolkata, and a presence in Japan, and Malaysia. It has set up affiliate institutes — TERI-North America in Washington, DC, USA, and TERI-Europe in London, UK.

TERI hosts the annual Delhi Sustainable Development Summit, which is swiftly gathering momentum as a major forum for the convergence of globally renowned leaders and thinkers dealing with the issue of sustainability.

With a staff strength of over 600, drawn from multidisciplinary and highly specialized fields, offices and regional centres equipped with state-of-the-art facilities, and a diverse range of activities, TERI is the largest developing-country institution working to move human society towards a sustainable future. TERI makes effective use of the latest developments in modern information technology in both its in-house and outreach activities.

TERI lays great emphasis on training, capacity building, and education. In 1999, it set up the TERI School of Advanced Studies, recognized as a deemed university by the University Grants Commission, India. The TERI School is evolving as a research university, offering doctoral and master's programmes in bioresources, biotechnology, energy, environment, and regulatory and policy studies.

Having celebrated its silver jubilee in February 2000, TERI is now poised for future growth, driven by a global vision and outreach, with a philosophy that assigns primacy to enterprise in government, industry, and individual actions.

WARWICK
BUSINESS SCHOOL

REVIEW OF GOOD PRACTICE IN MINED LAND REGENERATION

Mining & Energy
Research Network

Director: Professor
Alyson Warhurst

MERN

Submitted by:
Professor Alyson Warhurst
Dr Magnus Macfarlane
Dr Kevin Franklin and
Deborah Webb

Department for International Development

Project Number: R8173

PLANNING OF SUSTAINABLE REGENERATION IN MINING AREAS USING TRI-SECTOR PARTNERSHIPS

UNIVERSITY OF
WARWICK

Final Report
April 2004

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Appendix 1: Relevant Web Sites

1 Introduction

This report specifically addresses the regeneration of abandoned coalmines and abandoned iron ore mines. The biophysical and social issues and best practice responses are often similar or identical for both these types of abandoned mining operation. Therefore, for the purpose of this report they are treated collectively except where issues or best practice are sufficiently different to warrant individual analysis (see, for example Sections 26-28 dealing with acidic drainage, which is principally a coal mining issue). For both coal and iron ore it is not the intention of this document to provide a prescriptive guide to abandoned mine regeneration that can be used in every circumstance. The diverse aims and objectives of regeneration of abandoned mining operations make this an unrealistic expectation.

The location-specific nature of many of the potential biophysical and socio-economic issues means that a distinct group of responses will need to be developed for each individual project. No single all-purpose best practice exists or is likely to be developed in the future. Indeed, failure to account for the various external factors that significantly influence the implementation of best practice at project level is likely to lead to important site-specific factors being ignored or misjudged, with subsequent unwanted and unexpected flaws in the regeneration process. Therefore, the emphasis in this review is as much on the *process* of identifying appropriate best practice as it is about best practice itself.

For the reason described above, among other factors, there is no consensus on best practice, and there is no single authoritative text or source setting out how the process of regeneration should proceed, what its component parts should be, or defining the implementation of its practical elements at site level. This lack of consistency, has led to an increasing tendency to use the alternative term ‘good practice’, which reflects the position of many stakeholders that there can only be one ‘best practice’, while there are many ‘good practices’ that can be usefully applied according to context and need. This review uses the established ‘best practice’ term, but acknowledges that many stakeholders will see this as synonymous with ‘good practice’.

Although concepts may be transferred from site to site, a true solution depends on the abilities of all stakeholders to adapt a conceptual regeneration design to fit the context and requirements of the site. Best practice is therefore best viewed as a distillation of collective expertise and knowledge that should meet the following criteria:

- Widely accepted and applied.
- Enables legal compliance.
- Meets industry and community expectations.
- Includes suitable involvement and consultation.
- Gives appropriate consideration to indigenous peoples.
- Transparent.
- Integrated into the whole lifecycle of the mine.
- Sustainable, or leading to sustainability.

It may be acceptable to implement less sustainable measures in cases where the risks of doing otherwise are unacceptable. For example natural revegetation of wastes is likely to be the most cost-effective and energy efficient method that can be integrated with the surrounding environment. However, in cases where windblown dusts are a significant health risk for surrounding communities, a more proactive approach may be necessary, such as covers and capping and importation of new topsoil.

A global review of 'good practice', recently completed by the Global Centre for Post-Mining Regeneration underlined the fact that there is a distinct difference between the concepts of 'good practice' and 'best practice'. The review, undertaken by specialists acknowledged as world authorities in key relevant disciplines related to post-mining regeneration, also recognised the need to integrate a desire for global standards with the specific local and regional priorities that exist across the wide variety of social, environmental, and economic situations in which the mining industry operates.

Using a number of regional reviews, the research team:

- Collated, summarised and reviewed current policy documents.
- Identified key policy issues relating to mine closure and regeneration.
- Highlighted good practice that meets some or all of the principles defined by MMSD, documented the current status of good practice from the perspective of key regions of the world, and identified both the common themes of good practice as adopted regionally and locally and, where appropriate, highlighted the different local challenges and priorities that exist in some locations
- Documented case studies illustrating key components of good practice.

The application of technical, and socioeconomic knowledge in mine site regeneration was viewed as a means of achieving desired outcomes rather than an end in itself. Equally, it was recognised that multi-stakeholder interests and multi-disciplinary skills must be integrated to achieve a successful outcome in mine site regeneration and approaches, also a recurring thematic focus of the present review. Initial findings indicate that:

- The basic concepts underlying good practice tend to be common between different regions, but there is considerable difference in the emphasis given to them. In South Africa, for example, economic development, and improvement of health, living conditions and employment for the majority community are emphasised, whilst in Europe environmental protection is predominant.
- The differences between regions can be related to a combination of factors, including: the level of economic and social development; the importance of mining and minerals to the economy; the resources and powers available to regulators; and the influence of NGOs (further analysis is given below).
- The presence of the larger multinational mining companies is seen as a significant influence (since these are invariably at the forefront of developing good practice) and a clear contrast is emerging between these companies and smaller operators, who are generally more focussed on basic compliance with regulatory requirements. This difference is reflected at a national and regional level depending on the relative presence of the different sized companies.
- Throughout all regions, it is acknowledged that the closure of operations and regeneration of mine sites must be considered as part of the whole operational cycle. Many key elements of good practice (e.g., stakeholder involvement) are common to all operational phases. Therefore, attempts to address closure and mine site regeneration in isolation are regarded by many to be 'poor practice'.
- The level of technical, engineering and environmental knowledge available to the industry is seen as adequate in most cases (although there are exceptions where operations have been developed in areas where particularly vulnerable or poorly researched ecosystems exist). However, the integration of socio-economic considerations and improving stakeholder participation are seen as major challenges. For example, for most operations "stakeholder participation" is seen purely as a means of disseminating information on decisions already taken, rather than on encouraging more proactive involvement.
- Finally, before a consensus on the nature of good practice can be reached, the development of means by which the success of closure planning and site regeneration

can be assessed is essential. The confidence of stakeholders in the ability of industry to deliver the promised outcomes is heavily dependent upon the development of accepted validation criteria.

2 Defining Abandoned Mines

In general terms, abandoned mines have been defined as sites where advanced exploration, mining or mine production ceased without biophysical rehabilitation being implemented or completed, and with little or no mitigation given to socio-economic impacts on local and regional communities (Sassoon 2000).

The definition of abandoned mines, however, varies, which has significant implications for determining their numbers. UNEP (2000) estimate that the number runs into millions if every shaft, adit and alluvial working is included, and Appendix.28 (2002), documents some of the numerous abandoned mine inventories available for many regions of the world. However, no systematic worldwide or even comprehensive national inventory of abandoned mines exists, and, as a result, the further development of such inventories in the future will be necessary so that regeneration priorities can be set. There are a number of causes of abandonment, which have been identified by WOM Geological Associates (2000) to include:

- Completed mineral extraction.
- Unforeseen economic events caused early closure or left companies bankrupt (e.g. sudden drop in commodity prices, insurmountable mining or milling difficulties, and infrastructure problems).
- Abandonment of short-term exploration shafts and test pits in the period pre-dating core drilling for sample recovery.
- Absence of appropriate regulation with respect to mine reclamation until the latter part of the twentieth century.
- Absence of appropriate bonding systems to cover the costs of rehabilitation in cases where a mining company went bankrupt.
- Ineffective government enforcement, often due to a lack of capacity.
- Loss of relevant data recording location and nature of underground workings, surface openings and waste disposal areas. Loss of data was a common consequence of changes in data storage and management techniques, company bankruptcy, or unanticipated closure.
- Impacts of small-scale mining and uncontrolled occupation of mine sites by artisanal or illegal miners has occasionally led to site abandonment.
- Political unrest.

Typically, mine abandonment is an issue associated with historic operations, and today biophysical rehabilitation is viewed as a minimum legal requirement, with social and economic aspects of regeneration now rising up the agenda. However, the issue of abandoned mines clearly remains important to any country with a history of mining activity, and extends across every mined commodity, including coal and iron ore. Abandoned sites have long been recognised as an actual or potential threat to human safety and health and a cause of past and ongoing environmental, social impacts but also an economic liability for wider society (which may ultimately be required to pay for rehabilitation and regeneration). They are considered a negative legacy of the mining industry, demonstrating as it does a lack of care and planning in past practice and adherence to inadequate regulations (Appendix.28 2002).

3 Abandoned Mine Related Initiatives

The growing significance of abandoned sites is reflected in the continuing development of initiatives that are wholly or partly designed to address the complex biophysical and socio-economic issues associated with abandonment:

- The aforementioned *Global Centre for Post-Mining Regeneration* is a partnership of Eden Project, Rio Tinto, English Nature, Anglo American and MIRO, and is currently developing the business case for the Centre that will bring industry stakeholders together to address the major social (and cultural), economic, environmental and technical issues of mine closure planning. As part of the development process, a review of worldwide good practice was commissioned in June 2003 and the (as yet unpublished) results (see above) will ultimately form the most relevant context for this report.

- *National Orphaned/Abandoned Mines Initiative* (NOAMI) is a joint industry-government working group, assisted by other stakeholders, that reviews the issue of abandoned mines and develops partnerships in the implementation of remediation programs across Canada. Themes that have been identified as important to progress are:

    ➟ Building a national inventory.
    ➟ Community perspectives.
    ➟ Setting standards and rational expectations.
    ➟ Ownership and liability issues.
    ➟ Identification of funding models.

    Various Task Groups have been established under this programme to undertake in-depth analysis and to provide advice on the following key issues:

    ➟ Information Gathering
    ➟ Community involvement
    ➟ Legislative and institutional barriers to collaboration
    ➟ Funding models

    Although NOAMI is focused on the situation in Canada, it is anticipated that much of the work will be relevant to issues in other mining countries.

- *Mining, Metals and Sustainable Development* (MMSD) was initiated by the World Business Council for Sustainable Development. MMSD was an independent process of participatory analysis aimed at ‘identifying how mining and minerals can best contribute to the global transition to sustainable development’. This two-year project was designed to produce concrete results during its course and structures capable of being carried forward thereafter.

- *Cooperative Research Centre for Coal in Sustainable Development* (CCSD) is devoted to strengthening collaborative links between industry, research organisations and government agencies to achieve real outcomes of national, economic and social significance. CCSD commenced operations on 1 July 2001 as a joint venture consisting of eighteen participating organisations from the black coal producing and using industries and research organisations in Queensland, New South Wales and Western Australia. CCSD’s vision is to optimise the contribution of coal to a sustainable future and it will invest $61 million over a seven-year period in pursuit of this goal.

- Iron Mining Association – Environmental Committee.

- The Iron Range Resources and Rehabilitation Board (IRRRB) was given the authority to reclaim abandoned iron ore mine lands in 1978 and is funded by the Taconite Area Environmental Protection Fund. Six areas of concern are addressed by the IRRRB: safety, water pollution, erosion, air pollution, lack of vegetation, and aesthetics.

- The U.S. Federal Advisory Committee to Develop Innovative Technologies created the *Abandoned Mine Waste Working Group* to specifically address barriers to the development, deployment and commercialisation of innovative technologies to remediate abandoned mine waste. Part of the Group's conclusions was that technology development should be market-driven, and based on the needs of those involved in the clean up. In this way, the scientific and non-scientific site specific requirements are met by allowing a flexible response in terms of local site conditions, desired levels of remediation, cost and so on. To facilitate this, a lead organisation, existing as a partnership between public and private bodies, is required. This organisation would clarify the technology requirements in mine waste remediation, develop a priority list for technological solutions, and develop and promote a mechanism for technology transfer. Although this conclusion was developed in a U.S. context, the concept is sound and broadly applicable to scenarios in developed and developing countries alike.

- The *Acid Drainage Technology Initiative* (ADTI) was initiated in 1995 by federal agencies, the National Mining Association and the Interstate Mining Compact Commission to identify, evaluate and develop cost-effective and practical acid drainage technologies. The National Mine Land Reclamation Centre was selected, initially, to provide secretariat, project management and research services. In 1999, ADTI was expanded, through the addition of the metal mining sector group, which began organization efforts in 1998. ADTI now addresses drainage quality issues related to metal mining and related metallurgical operations as well as acid drainage from coalmines, for future and active mines as well as for abandoned mines. ADTI recognizes the distinction between technology development and its implementation in the regulatory process. ADTI is a technology development program. It is not a regulatory or policy development program.

- *International Council on Mining and Metals* (ICMM). The ICMM adopted the following Sustainable Development Charter, which was first developed and accepted by its predecessor organisation, ICME: "*The production and availability of a broad range of metals is essential to modern life. Throughout human history, social and economic progress has been dependent to a large extent on the availability and use of metals. Assured supplies of metals will be required to meet the needs of the world's growing population and to help fulfil expectations of improvement in the quality of life, notably in developing countries. Given their unique physical and chemical properties, metals are essential for a number of uses in transportation, housing, power generation and transmission, and electronics, as well as for a wide range of high technology applications in the telecommunications, computer, aerospace, medical and environmental control industries. Metals can also be reused and recycled indefinitely without loss of their properties. Exploration, extraction and primary metal processing activities create wealth and enable ICMM members to meet society's requirements for metals while contributing to sustainable development and enhancing shareholder value. Approached in a responsible manner, such activities will help alleviate poverty, particularly in remote areas, and foster sustainable* *improvements in the health, education, prosperity and the standard of living of communities. Thus, mining and metal production can serve as catalysts for regional economic and social development. Some ICMM members are also in a position to contribute to biodiversity conservation and the conservation of ecological and cultural values in protected areas adjacent to their operations. The commitment of ICMM members to recycling also provides important opportunities to extend the use of these materials, conserve resources, reduce energy usage, minimise waste disposal and contribute to the needs of future generations. ICMM members accept the importance of responsible management of their operations from discovery to closure. They are able to contribute to the scientific knowledge on the safe production, use and disposal of metals. They are also committed to adopting appropriate measures and to implementing enhanced risk management strategies, based on sound science, valid data, effective public consultation and understanding of community cultures and needs, in order to minimise adverse environmental and community impacts. Neither their operations nor their products should present unacceptable risks to employees, communities, customers, the general public or the environment…It is also acknowledged that consultation and participation are integral to balancing the interests of local communities and other affected organisations and to achieving common objectives. From the perspective of ICMM members, society's pursuit of sustainable development is a dynamic process that will continue to evolve over time in response to changing social values and priorities. Sustainable development involves values and principles that guide the corporate policies and practices that enable ICMM members to contribute to economic, social and environmental progress as well as to institutional and technological advances*".

- *Mitigation of the Environmental Impact from Mining Waste* (MiMi) is financed by the Swedish Foundation for Strategic Environmental Research and focuses on the improved, economically efficient management of mine waste within Sweden.

- *Mine Environment Neutral Drainage 2000* (MEND 2000). This was a three-year program that officially started January 1998. The Mining Association of Canada (MAC) and Natural Resources Canada funded the program equally. The key to MEND 2000 was technology transfer, providing state-of-the-art information and technology developments to users via workshops, reports and online services. Long-term, field scale and other key projects initiated under MEND were also being pursued. Through these efforts a further reduction of the environmental liability associated with acidic drainage will be realized.

  The MEND 2000 objectives were:

  - Transferring the knowledge gained from MEND and other related acidic drainage projects.
  - Verifying and reporting the results of MEND developed technologies by long-term monitoring of large-scale field tests.
  - Maintaining a link between Canadian industry and government agencies for information exchange and consensus building.
  - Maintaining linkages with a number of foreign government and industry driven programs.

- *International Network for Acid Prevention* (INAP) is an industry based initiative that aims to globally coordinate research and development into the management of sulphide mine wastes. The principal objectives of INAP are to promote significant improvements in the management of sulphidic mine materials and the reduction of liability associated with acid drainage through knowledge sharing and research and development of technology. To meet these objectives INAP will:

- Achieve a significant reduction in the liability associated with mine materials through information sharing, collaborative research and implementation of best management practices through the complete mining business cycle.
- Build credibility with key stakeholders through their engagement in the affairs of INAP and the collaborative development of a worldwide guide based on best management and technical practices as applied to acid prevention and control.
- Establish an organisation with demonstrated structure and abilities to make long-term improvements in acid prevention and other environmental issues on the basis of global cooperation and action.

- *US Department of the Interior's (USDI) Abandoned Mine Lands Program*. Working with the US Geological Survey, the US Forest Service, the US Environmental Protection Agency and western state governments, the USDI has undertaken work to identify and prioritise sites on Bureau of Land Management, National Park Service and US Forest Service administered land. The primary focus is the clean up of abandoned and inactive mine sites.

4 Defining Regeneration

Ideally, according to Coppin and Box (2000), a mineral operation, as a temporary use of the land, should not impose any permanent constraints on the options for future beneficial use of the site and adjacent land, nor have any permanent effects on the local water resources, biodiversity and overall landscape quality or associated socio-economic development. However, in the case of abandonment, residual biophysical and socio-economic impacts may be significant and varied. Therefore, in most cases regeneration will have many facets. There are three main regeneration strategies:

- A 'walk-away' approach, where there are no residual constraints on the future use of the land remaining after regeneration has been completed, no potential for the recurrence of socio-economic issues and where there are no additional monitoring or maintenance requirements.
- 'Passive care' where there is a need for minimal monitoring of the biophysical and socio-economic environments.
- 'Active management' requiring regular monitoring and changes/refinement of the biophysical and socio-economic environments.

In practical terms, the first of these strategies is likely to be extremely rare. In some cases, regeneration may simply address and rectify biophysical impacts (e.g. if urban and rural populations are sufficiently distant from the abandoned site that it can be considered in isolation). In other cases regeneration may focus primarily on economic and social aspects if abandonment has not created any significant impacts on the biophysical environment. However, in most cases, the creation of new, sustainable socio-economic benefits is undertaken jointly with biophysical remediation (Clark et al 2000). Therefore, the regeneration of abandoned coal and iron ore mines typically entails restoration or improvement of the biophysical environment, and the creation or revitalisation of a sustainable social and economic infrastructure and framework.

To understand the different aspects of regeneration it is important to have a consistent set of definitions. The following are adapted from Coppin and Box (2000):

- *Decontamination* is the removal or destruction of naturally occurring or manmade materials and chemicals that have potential to cause harm to human or ecosystem health and the productivity of the host medium (normally land, water or air).

- *Reclamation* is a widely used term to describe the process of creating a land-use, which may be hard (industrial, commercial) or soft (agricultural, amenity), on a site where mining operations have ended. Reclamation generally involves the dismantling of buildings and structures, and the stabilisation and revegetation of waste rock dumps and tailings disposal areas. The costs of such are relatively easy to predict. However, for a limited number of sites, there may be a requirement for ongoing environmental management long after site closure, making the costs impossible to accurately quantify (e.g. treatment of acid rock drainage).

- *Rehabilitation* has a broadly similar meaning to reclamation, though it implies that the after-use is related to land-use on the site prior to the mining activity.

- *Restoration* is often used to mean restoring the original land-use or vegetation, or even the same landform. It is also applied to active mineral operations where the mineral operator develops the after-use as part of the site activities, rather than starting with an abandoned or derelict site. Generally, prevention is better than cure, and it is closer to the ideals of sustainable development if closure and decommissioning of a mine is undertaken, and paid for, as part of the operational phase (i.e. site reclamation is not left until operational revenue flow has ceased).

- *Revegetation* is the process of vegetation establishment and aftercare undertaken as part of reclamation, rehabilitation or restoration. Revegetation may be with local or non-local species depending on the chosen end-use.

- *After-use* or *end-use* means a land-use to which a site is returned, which should be beneficial although not necessarily in an economic sense (e.g. amenity or wildlife value, preservation or enhancement of biodiversity).

- *Aftercare* describes the process of managing the soils and the vegetation systems after the initial revegetation in order to ensure that the desired after-use is attained within a reasonable time period.

5 Regeneration Objectives

Biophysical regeneration is often the enabling factor with respect to social and economic regeneration in as much as the degree of social or economic intervention or ‘engineering’ is set in part by the ability to restore the biophysical environment to a form that is suited to the needs and wishes of key stakeholders. In particular, the aims and objectives of the regeneration should be based on the actual needs and resources of the local community if they are to be sustainable in the long term. According to Sassoon (2000), the additional objectives of sustainable regeneration are likely to include a number of the following:

- Protection of public health, safety, general welfare and property from the adverse effects of past mining practices which constitute an unacceptable risk.
- Prevention of continued biophysical impacts.
- Restoration of degraded land and water (and ecosystems to which they play host) including conservation and development of soil, water, land, wildlife, recreation resources and agricultural productivity as appropriate to the desired end-use.
- Rectification of aesthetic impacts.

- Protection, repair, replacement, construction and enhancement of essential and non-essential facilities and infrastructure such as roads, health clinics or recreation and conservation areas adversely affected by abandonment.
- Generating wealth through job creation (with concomitant capacity-building to ensure local people can compete for jobs outside the immediate area).
- Self-help schemes like downstreaming, multi-skilling, to encourage local people to generate a sustainable economic and social infrastructure.
- Ensuring that communities have the necessary skills and resources to continue development programs after the regeneration process has been completed.
- Economic diversification of the community, depending on the nature and size of the present economic base, infrastructure of the area, community solidarity, and government support. Mining communities may be isolated, making the cost of transport high and, therefore, the profitability of manufacturing projects low.
- Long-term compatibility of the regenerated site with the surrounding land and socio-economic context.

As previously noted, the practices contained in this review represent a mixture of 'good' and 'best' practice drawn from those that are well known and that have been shown to be effective when used appropriately. However, once again it is important to recognise that 'best practice' is constantly evolving and must be adapted to each specific site and its biophysical and social and economic environment, for example:

- End-use issues (e.g. community needs and perspectives, other stakeholder perspectives, legal requirements, land ownership, indigenous land values).
- Local hydrological conditions and water availability
- Soil types and availability and land capability.
- Topography and visibility of area.
- Climate (e.g. minimum and maximum temperatures, prevailing wind direction).
- Proximity of urban/rural populations and indigenous peoples.
- Degree of post-regeneration management available.
- Scale of site requiring regeneration.
- Site-specific risk assessment and prioritisation (including risks to stakeholders and land/water resources outside of the regenerated area, e.g. sensitivity of receiving waters downstream of the regenerated site or presence of conservation areas wholly or partly within or adjacent to regeneration area).
- Extent of biophysical reclamation completed prior to abandonment.
- Risk of natural hazards (e.g. fires, flooding).
- New technologies are often developed that will change the approach to mine regeneration. An example provided by Appendix B (MMSD 2002) is that of gold heap leach facilities, which in the 1980s called for rinsing with fresh water at mine closure to reduce pH and cyanide. It has since been proven that it is generally heavy metals and salts that are of greater environmental concern, and that a different process is required. Similarly, improved technology can lead to improved re-treatment of tailings or other mined materials.
- Regional context (e.g. existing industry in local area and wider region).
- Time available to complete the regeneration process.
- Economic Climate. The results of a study carried out by DfID and British Geological Survey in Namibia and Costa Rica suggest that changing economic conditions can dramatically affect the viability of re-utilisation or recycling of mine tailings both during and after mining (Harrison et. al. 2003).

6 Overview of Biophysical Regeneration

With respect to the biophysical dimension, Ricks (1997) identifies the main components that should be addressed during regeneration as including:

- *Underground mine workings*: shafts, adits, declines and ventilation raises should be sealed, the possibility of leachate from backfill should be considered and addressed, and the potential for the short- medium and long-term generation of acid rock drainage assessed and preventative/remedial action taken.
- *Open pit workings*: stability of slopes and benches, management of rainwater and groundwater, prevention of unauthorised access to the site, potential for the contamination of surface waters with metals, other contaminants and suspended solids, potential for the contamination of groundwater with metals and other contaminants, backfilling (if appropriate) should be considered an option, reinstatement of haul roads.
- *Mineral processing and smelting building and general areas*: removal of surface structures and foundations, removal of fixed and mobile plant, assessment and clean up of work areas, including those where chemicals and fuels were stored, disposal of all scrap materials and non-mineral wastes, re-profiling of areas, revegetation.
- *Waste rock and overburden disposal areas*: use for landscaping operations if appropriate (i.e. no environmental hazard associated with their use) for example in re-profiling, screening, establishment of vegetation, assess (and rectify) slope stability of dumps of unused material, assess and propose preventative or remedial actions for potential contaminated leachate, implement preventative measures to prevent water and wind erosion, modify to minimise visual impact.
- *Tailings disposal areas*: long-term geotechnical stability, assess potential for short-, medium- and long-term generation of contaminated leachate and implement suitable preventative or remedial actions, provision of long-term surface water management strategy, implement preventative measures to prevent water and wind erosion, prevent unauthorised access, implement dewatering and revegetation strategy if appropriate.
- *Water management facilities*: restoration of dams, reservoirs, settling ponds, culverts, pipelines and spill ways, treatment and/or disposal of water treatment plant sludges, long-term management of surface drainage and effective discharge of water minimising risk of contamination.
- *Landfill and waste disposal facilities*: implement final closure strategy, which may include sealing, covering and revegetation, removal of associated plant and buildings, consideration of potential for groundwater and surface water contamination and implementation of appropriate preventative or remedial strategy, prevention of illegal dumping of household and industrial wastes.
- *Infrastructure*: removal of power and water to site (unless indicated otherwise by socio-economic conditions), reinstatement of haul and access roads (unless required by legitimate non-mining operations in the area/region).

Any or all of these and site-specific variations may be present at abandoned coal and iron ore mines.

7 Stakeholder Identification and Consultation

Appendix.28 (2002) states that ‘the role of public opinion is paramount in the design of mine closure and regeneration plans’. Stakeholders with an interest in regeneration can be those that have been impacted in some way by the abandonment process, or by the abandoned site itself, and those that may benefit in some way from the regeneration process. ANZMEC (2000) note that this will generally include local communities, workers, civil society organisations and government agencies.

Two primary general rationales emerge from the literature in support of stakeholder consultation. The first is that there is a moral obligation, as it honours the widely held principles of democratic decision-making. The second is that stakeholder consultation provides a means of identify the most appropriate strategy for a given environment, and therefore has greatest chance of being broadly acceptable. A number of further advantages of stakeholder consultation, both generally and in the context of post mine regeneration planning and decision making, are identified in the literature (e.g. Copenhagen Charter 1999, IFC 1998, Macfarlane 2002, World Bank 1993) including:

- Developing realistic employee, community and regulatory expectations.
- Establishing a satisfactory post-closure land-use agreeable to all.
- Understanding and mitigating stakeholder issues and concerns.
- Complying with national and regional standards and regulations.

While it is clearly not possible for abandoned mines, ANZMEC (2000), Macfarlane (2001), Petts (1999) and Sassoon et al (2002), all argue that for the regeneration process to be fully effective there is a need for consultation with local communities to occur at both earlier and later stages of the mineral project than has traditionally been the case. Consultation needs to move from an almost exclusive focus on the operation period to be given a similar emphasis during the exploration and closure phases, with a particular emphasis on involvement at the following stages:

- Site assessment and investigations (e.g. local knowledge of biophysical issues, community perspectives on end-uses for regenerated sites).
- Assessment of regional context (e.g. information on wider biophysical, economic and social issues).
- Assessment of appropriate end-uses (e.g. local knowledge on what has been attempted before, end-uses that would ‘fit’ with existing characteristics of the biophysical, economic and social environments).

However, whenever conducted, consulting with stakeholders is not just about holding a public meeting to present the company or government’s pre-determined regeneration plan. It is a two-way exchange where all participants should feel that their input is valued and influences planning (ANZMEC 2000). For Gonella et al. (1998:25), conventional approaches to stakeholder consultation ‘repeatedly fail to uncover, predict, or effectively respond to the deeper social and ethical concerns’ because it is a static one-way mode of communication. In this respect, Macfarlane (2002) notes that some companies and governments are taking advantage of stakeholders (‘capitalising on the social’) rather than really engaging with stakeholders (‘socialising the capital’). This under-utilises the potential of stakeholder consultation to enhance decision-making, and will alienate key stakeholders.

To avoid this situation, those responsible for mine regeneration should adopt a progressive attitude based on the underlying philosophy that: ‘…the potential for public acceptance is directly proportional to the amount of control you are willing to relinquish, and inversely proportional to the walls behind which you try to hide’ (Taylor et al 1995). Indeed, according to Silanpaa (1999:20) ‘…it would be desirable to further widen the contextual scope of the consultation process to solicit the stakeholder views relating to the ecological and economic dimensions of development in addition to the social dimension. Similarly, in terms of rehabilitation of the environment, Mitchell (1999) suggests that it is necessary that there is reasoned debate between all stakeholders, but states that at this more technical level it is particularly important that this occurs between operators (where identifiable in the case of abandonment) and regulators, in rigorously defining the most economically viable options for rehabilitation.

The World Bank and IFC (2002) highlight the case of the Misima mine in Papua New Guinea for what can happen if consultation is neglected in mine planning. Here, a state-of–the-art hospital was built for the community, only for the mining company to subsequently discover that what the community wanted was much more basic health care, including better access to everyday medicines and inoculations, as well as some modest improvements in water supply and sanitation. Had the company undertaken community consultation in designing the mine and considered the implications for mine closure, it would have looked at how it could work with local government to provide more of the everyday health services that they required, and so generated health care services that are ultimately less costly and more sustainable after closure or abandonment.

8 Site and Regional Assessments

Assessments of the abandoned site characteristics and the regional context are the second stage in the regeneration process. Only by understanding the nature of the site is it possible to determine the best practice measures that must be implemented, and only by knowing the regional context can the most appropriate end-use for the regenerated site be identified. Assessments will include both biophysical and socio-economic elements. Social and Environmental Impact Assessment along with risk assessment are tools that are appropriate for this purpose. Becker (1997:2) defines Impact Assessment (IA) as *the process of identifying the future consequences of a current or proposed action*. The IA process can be regarded as providing direction in; (1) the identification and understanding of the likely impacts stemming from change; (2) the prediction and mitigation of likely impacts from change strategies that are to be implemented and; (3) the development of appropriate monitoring programs to identify and manage unanticipated impacts that may develop as a result of the change strategy (Burdge and Vanclay 1995).

A useful matrix by the Interorganisational Committee on Guidelines and Principles relates the closure and regeneration project stage to social impact variables for SIA and is reproduced below (ICGP 1995). This is reproduced in Table 1. Similar checklist environmental variables have been produced for EIA at closure and regeneration (Petts 1999). The introduction of these criteria explicitly to help identify and predict the effects of both closure and abandonment and to inform the design of an appropriate closure and regeneration management plan is just one example of the way in which E/SIA can benefit mine or post-mine development (Macfarlane 1999).

Table 1. Matrix relating project stage to social impact assessment variables

Social Impact Assessment Variable	Decommissioning / Abandonment
Population Characteristics	
Population change	
Ethnic and racial distribution	
Relocated populations	
Influx or outflow of temporary workers	
Seasonal residents	
Community and institutional structures	
Voluntary associations	
Interest group activity	
Size and structure of local government	
Historical experience with change	
Employment / income characteristics	
Employment equity of minority groups	
Local / regional / national linkages	
Industrial / commercial diversity	

Presence of planning and zoning activity	
Political and social resources	
Distribution of power and authority	
Identification of stakeholders	
Interested and affected parties	
Leadership capability and characteristics	
Individual and family changes	
Perceptions of risk, health and safety	
Displacement/ relocation concerns	
Trust in political and social institutions	
Residential stability	
Density of acquaintanceship	
Attitudes towards policy / project	
Family and friendship networks	
Concerns about social well being	
Community resources	
Change in community infrastructure	
Native American tribes	
Land use patterns	
Effects on cultural, historical and archaeological resources	

For site and regional impact assessments, there are a number of key preliminary steps:

- Define the project team, chain of command, responsibilities etc.
- Define potential concerns – what are the issues that need to be considered?
- Select a methodology – how will the site/region by characterised and assessed?
- Define the initial information requirements – where should the assessment begin?
- Evaluate existing information – are data sufficient to define concerns?
- Define additional data requirements – what other data are required?

Subsequently, more detailed information must be acquired, including:

- Background information.
- Site mineralogy and geology.
- Infrastructure assessment.
- Water management (pre- and post-abandonment).
- Rehabilitation efforts (started and/or completed).
- Assessment of existing biophysical environment (including assessment of pre-abandonment environmental baseline if available).

Background information
- Status of the project site.
- Ownership structure (if known or relevant).
- Project objective (e.g. preliminary assessment of end-use).
- Legislative requirements with respect to regeneration.
- Significant features of the locality (e.g. waterways, wetlands, cliff lines, heritage sites, important food producing areas).

Site mineralogy and geology
- Assessment of previous mining activity.
- Anticipated ‘problem’ minerals (e.g. salts, sulphides).
- Geological setting and structures.

- Physical and chemical characteristics of overburden and wastes.
- Residual coal or iron ore estimation.
- Valuable by-products estimation.

Infrastructure assessment
- Access, presence and use of existing tracks and roads.
- Permanent and temporary earthworks.
- Mining-related buildings and plant.
- Processing plant and related equipment.
- Power supplies.
- Water supplies.
- Fuel storage and transfer.
- Maintenance and repair workshops.
- Laboratories.
- Temporary or permanent accommodation.
- Sewage and garbage disposal.
- Medical centres and clinics.

Water management (pre- and post-abandonment)
- Water management strategy.
- Available water resources (e.g. surface waters, groundwater, piped freshwater).
- Local, regional and national significance of water resources.
- Anticipated water consumption requirements (scenario building for different end-uses).
- Water control system (e.g. existing provision of controls for runoff, groundwater, potable water supply, domestic and process wastewaters).
- Definition of extreme flow rates.
- Definition of normal flow rates.
- Hydrological and geochemical considerations (e.g. acid producing potential, element solubility, salinity status).

Rehabilitation efforts
- Legislative requirements.
- Preliminary assessment of post mining land use (in wider regional context) - alternatives and preferred option(s).
- Assessment of landform design options.
- Estimated post-regeneration land capability.
- Assessment of existing revegetation efforts.
- Development of preliminary land management plan.

9 Biophysical and socio-economic impacts of coal and iron ore mining and abandonment

A comprehensive assessment of the biophysical and socio-economic impacts of coal mining and iron ore mining and related mine abandonment is outside the scope of this paper, and only a brief review is offered below. However, there are a number of key texts that should be highlighted that review such impacts in greater detail:

- Brown, M., Barley, B. and Wood, H (2002) ‘Minewater Treatment. Technology, Application and Policy, IWA Publishing, London, ISBN: 184339 004 3, 453 pp.
- Chadwick, M.J. (1989) ‘Environmental Impacts of Coal Mining and Utilization: A Complete Revision of Environmental Implications of Expanded Coal Utilization’. Elsevier Science & Technology Books.
- Hester, R., and Harrison, R. (1994) ‘Mining and Its Environmental Impact’. Royal Society of Chemistry, Cambridge.

- Ripley, E. A., Redmann, R. E., and Crowder, A. A. (1996) 'Environmental Effects of Mining' St. Lucie Press, Delray Beach, Florida.
- Sengupta, M. (1992) 'Environmental Impacts of Mining: Monitoring, Restoration and Control'. Lewis Publishers, Boca Raton.
- United Nations, United Nations Department for Development Support and Management Services and United Nations Environment Programme (1994) 'Environmental Management of Mine Sites'. Technical Report No.30.
- World Bank (1998) 'World Bank Pollution Prevention and Abatement Handbook, Coal Mining and Production', July 1998.
- World Bank (1998) 'World Bank Pollution Prevention and Abatement Handbook, Base Metal and Iron Ore Mining', July 1998.
- U.S. Environmental Protection Agency (1994) 'Technical Resource Document: Extraction and Beneficiation of Ores and Minerals. Volume 3: Iron' August 1994.
- Haigh, M. J. (ed). (2000) 'Reclaimed Land. Erosion Control, Soils and Ecology', A.A. Balkema, Rotterdam, ISBN: 90 5410 793 6, 400 pp.
- Institute of Quarrying (2004) 'Environmental Protection Handbook', Institute of Quarrying, Rugby, UK (in press).
- 'Proceedings of the Second International Conference on Tailings and Mine Waste 1995', ISBN 90 5410 526 7, Rotterdam/Brookfield.
- 'Proceedings of the Third International Conference on Tailings and Mine Waste 1996', ISBN 90 5410 594 1, Rotterdam/Brookfield.
- 'Proceedings of the Fourth International Conference on Tailings and Mine Waste 1997', ISBN 90 5410 857 6, Rotterdam/Brookfield.
- 'Proceedings of the Fifth International Conference on Tailings and Mine Waste 1998', ISBN 90 5410 922 X, Rotterdam/Brookfield.
- 'Proceedings of the Sixth International Conference on Tailings and Mine Waste 1999', ISBN 90 5809 025 6, Rotterdam/Brookfield.
- 'Proceedings of the Seventh International Conference on Tailings and Mine Waste 2000', ISBN 90 5809 126 0, Rotterdam/Brookfield.
- 'Proceedings of the Eight International Conference on Tailings and Mine Waste 2001', ISBN 90 5809 182 1, Rotterdam/Brookfield.
- 'Proceedings of the Ninth International Conference on Tailings and Mine Waste 2002', ISBN 90 5809 353 0, Rotterdam/Brookfield.
- Minnesota Department of Natural Resources. 1980. Rules relating to mineland reclamation, Chapter 6130 http://www.revisor.leg.state.mn.us/arule/6130/

Although drawn from generic issues seen across a range of mined commodities, all the impacts described below have some *potential* to be an issue at abandoned coal and iron ore mines. Many of these are related to land-loss or sterilisation with both coal and iron ore production involving the acquisition of large areas of land for underground (coal) and opencast (coal or iron ore) mines. For example, in India, more than 680,000 hectares of land is under mining lease and experts estimate that in 2000 opencast coalmines alone will cover some 100 km^2). According to Noronha (2000) the iron ore industry in Goa alone operates in a region of 500 km^2, with annual production of iron ore in this region averaging 12-13 million tonnes per year (approximately 25% of the India's iron ore production and 55% of its exports). Biophysical, social and economic impacts can be viewed from a number of different perspectives and categorised in a number of different ways. The preferred categorisation will vary according to the interests and requirements of particular stakeholders.

The following section briefly examines biophysical and socio-economic impacts in seven categories that form the most common concerns for stakeholders:

- Chemical impacts (e.g. contamination of water and land).
- Physical impacts (e.g. dust, suspended solids in water and erosion).
- Solid waste generation (e.g. mining and processing-related wastes).

- Aqueous effluent generation (e.g. acidic drainage).
- Individual and family level socio-economic impacts
- Community level socio-economic impacts

Chemical impacts (major potential – coal, minor potential – iron ore)

Chemical pollution is one of the most serious, most hazardous and long-term forms of environmental impact. Such pollution can occur in surface water from site drainage, in groundwater through percolation, in air through atmospheric emissions and through the disposal of wastes and subsequent contamination of soils. While chemical pollution can derive from improperly handled chemicals used in processing (introduced chemicals), most chemical pollutants originate from the mined materials and associated wastes themselves.

Many trace metals are associated with coal deposits, often in the form of sulphides (particularly pyrite – FeS_2) or salts. This is less common in the case of iron ores, although the presence of sulphides has been well documented at a number of major iron ore operations, and pyrite (FeS_2) deposits are sometimes worked as a source of iron ore. However, although over 300 minerals contain iron, only three largely inert minerals are considered to be primary iron ore sources (magnetite, hematite and goethite). Therefore, for the purpose of this report it can be stated that in general terms the risk of chemical pollution from most iron ore mines is relatively small compared to coal, and the following paragraphs will focus on coal operations alone.

World wide about 1 billion tons of iron ore is produced each year. Iron ore is mined in about 50 countries with the seven largest of these producing countries accounting for about three-quarters of total world production. Australia and Brazil together dominate the world's iron ore exports, each having about one-third of total exports. About seventy percent of production is from natural iron ore (primarily hematite, Fe_2O_3) and about 30% is produced from magnetite (Fe_3O_4). Natural ores require little to no processing while magnetite requires crushing, grinding and magnetic separation. Substantially more waste is produced from magnetite operations.

Sulphides and salts are largely removed from raw coal and iron ore due to the fact that their presence decreases the value (and saleability) of the final product and would otherwise cause a number of environmental impacts during subsequent use of the coal (e.g. sulphur dioxide generation during coal combustion). Therefore, associated wastes (and residual in-situ coal deposits which cannot be economically recovered) are often contaminated with significant concentrations of potentially damaging contaminants. When sulphides are exposed to water and oxygen they normally oxidise to produce a metal-contaminated acidic effluent.

The consequences for the environment of contamination by acidic effluent or toxic trace metals can be disastrous, particularly as the process of acid generation often continues for many years or even decades. Equally, salts (e.g. chlorides and sulphates) are often water soluble, and will readily dissolve and migrate into surface and groundwater. Heavy metals, even in small amounts can be harmful to human and ecosystem health, and chlorides/sulphates may also cause significant impacts. For this reason, water discharge standards are often based on health criteria, rather than the capacity of individual receiving water bodies to assimilate the waste. Contamination of groundwater or surface waters may result in the loss of beneficial uses, such as drinking water supply, fisheries, irrigation, wildlife resource and recreation (including ecotourism). Groundwater aquifers may be hydraulically connected to a relatively distant surface water body, where the pollution problems may ultimately reappear (this is a good example of a secondary impact). Wind dispersion of fine metal contaminated particulates (wastes and coal) may also result in secondary impacts on adjoining land (which may become contaminated), while water erosion (see for example Figure 1) may transfer contaminated materials to surface waters and associated sediments where impacts on benthic ecosystems may become apparent.

Figure 1. Significant rainfall erosion of waste stockpile, northern Minnesota

Physical impacts (major potential – coal and iron ore)

Physical impacts are generally linked to the handling, management and disposal of solid wastes associated with coal or iron extraction and processing. Although conditions will vary according to site conditions and geology, in general terms a significant portion of the material extracted during coal mining is ultimately sold or used on-site (i.e. coal, overburden, stripped soils). Consequently, the waste generation associated with coal mining is lower than that for base and precious metals (where the valuable component may vary from a few percent to a few parts per million). Equally, iron is an abundant element in the earth's crust and is present in many areas. Therefore, it is of relatively low value and ore deposits must have a high iron percentage to be considered economically viable. Generally a deposit with more than 25% iron is considered to be potentially suitable (USEPA, 1994a). Thus, as is the case for coal, waste generation may be relatively low compared to some other mined commodities. However, for both coal and iron ore mining, although the relative ratio of waste to commodity may be low, the absolute values for waste production may still be significant due to the size of the operations.

Damaging physical impacts can include suspended solids in water, eroded land, subsequent blanketing of aquatic ecosystems by silt layers, dust in air, or land degradation from prior inappropriate disposal of solid waste. Large amounts of suspended solids in surface waters emanating from abandoned mines are indicative of poor waste management practices, inadequate erosion control measures and may also be accompanied by chemical water pollution (in the case of coal mining operations). In the absence of proper erosion control at abandoned mines and rehabilitated sites, erosion of cleared areas and of dumped waste material can take place, resulting in elevated sediment loads in runoff during periods of rainfall. With particular respect to coal mining, if these sediments contain reactive minerals such as sulphides (particularly pyrite) it can extend the environmental footprint of the mining operation by the transfer of acid generating minerals and metal contaminants in a form that can readily become bioavailable and soluble.

Additional physical impacts may result from the presence of surface and underground voids. Subsidence at both coal and iron ore underground operations may result in surface manifestations and damage. Depending on the local hydrology, surface voids may fill with water. In general the water quality will be a reflection of local groundwater conditions and in many areas the water quality can be quite good and the abandoned pits have been used for recreation and water supply.

Iron is generally mined using surface operations (e.g. open-pit and open-cut), while coal is extracted using both surface and underground methods. However, if iron ore is present at depth underground mining methods may be employed. Noronha (2000) notes that physical impacts are evident in India from huge ‘holes in the ground’ and the ‘artificial mountains’ of dumped overburden, and in the crop and non-crop land downstream of mining dumps affected by surface runoff from these dumps. She also notes that mining activity in Goa has resulted in the loss of forest cover, loss of agricultural land and the deterioration of agricultural soil conditions, all of which can be considered physical (and indeed socio-economic) impacts.

According to Noronha (2000) during the period 1980-90, 146.75 million tonnes of iron ore were mined in Goa. With an average stripping ratio of 2.5 $m^3\ t^{-1}$, this implies that 366.88 million m^3 of waste were generated during this period, or approximately 37 million m^3 per year. The amount of land required for dumping depends on the height of the dump; for an average dump height of 35 metres, approximately 3 hectares of land is required to dump a million m^3 of overburden waste. Thus, for an annual waste generation of 37 million m^3 the mining industry may have an annual requirement of 111 hectares outside the mining concessions in which to dump the overburden.

The current debate regarding iron ore mining in the Kudremukh National Park demonstrates how important the physical impacts associated with operating and abandoned mines can be. The National Park and adjacent areas have significant biodiversity-rich evergreen forest and shola-grassland ecosystems, and contain a number of endangered species populations, and the related river systems contain a number of rare and endangered species. The Kudremukh Iron Ore Company Limited’s mining operation in the hilly Western Ghats region of India receives amongst the highest rainfall of any opencast mining operation in the world (6-7 m a year). Topography, rainfall characteristics, and opencast mining activities have combined to result in high sediment discharges to the river system, spreading the physical impacts far beyond the site boundaries. While the iron ore tailings are not toxic they may cause severe damage to the river environment as they as they settle and choke the riverbed and degrade the quality of the water.

Large amounts of airborne dust may result in reduced visibility and can also have adverse effects on human health, causing respiratory problems and general discomfort. High concentrations of particulate matter in the air have the potential to cause damage to buildings and cause operational damage to machinery and equipment (Appendix.28 2002).

Solid waste generation (major potential – coal and iron ore)

The major source of solid waste from coal mining is extraction and subsequent processing. Depending on the point at which it is rejected from the process, waste may be disposed of in a coarse as-mined state (e.g. waste rock) or as fine tailings. If on-site combustion of coal has also been undertaken, fly ash may also be present. Other waste products may include dusts, sludges from water treatment and sub-economic coal. These various wastes may contain significant quantities of the metal sulphides (particularly pyrite, as noted above) and other metal compounds and chemicals (such as salts and various combustion products).

Materials generated as a result of iron ore mining include the soil over the bedrock (overburden), waste rock (rock with insufficient iron content to be considered ore) and processing wastes (e.g. tailings arising from magnetic separation, flotation, and gravity concentration activities). Of these, the material generated in the largest quantities by iron ore extraction is the material that overlies the ore body (the overburden) and the other rock that has to be removed to gain access to the ore (the mine development rock and waste rock). For overburden and soil stockpiles the major concern is soil erosion. By applying best management practices of sloping, controlling lift heights, constructing benches, and establishing vegetation, most erosion problems can be prevented. Vegetation can usually be established directly on the soil given suitable fertilizer and appropriate vegetation.

The quantity and composition of waste rock vary greatly between sites, and therefore their potential for causing impacts also varies. The major concern is drainage quality. The volume of water is a function of the watershed area and the local climate. The quality of the drainage is a function of the physical, chemical and mineralogical composition of the waste. The primary minerals of concern are sulphides. Since most iron production is from formations that contain oxidized ore, the amount of waste generated that contains sulphides is usually small. As noted above, problems can develop if the mine is located on a geological contact between the iron formation and a sulphide rich formation. Therefore it is critical that all wastes are characterized prior to initiating operations. Special handling may be required depending on the composition of the waste and the environmental risks. If sulphide minerals are not present, drainage is generally circumneutral but will contain elevated concentrations of total dissolved solids and increased hardness. Nitrate concentrations will be elevated initially due to residuals from blasting agents that are commonly ammonium nitrate and fuel oil (ANFO). Nitrate concentrations tend to decrease with time after the stockpile has been completed.

Tailings are the discarded material resulting from the concentration of ore during processing of the iron ore. They are characterised by fine particle size, but have varying mineralogical and chemical composition depending in the local geochemistry. Large tailings basins are needed for magnetite operations. Most operations reclaim water from the basin to use in processing. Tailings basin water is generally slightly alkaline and contains elevated levels of dissolved solids but low levels of metals. Since these basins are often unlined, water is lost to groundwater and as seepage from the base of the impoundment. Although the interior of these basins can be vegetated by applying inorganic fertilizer, appropriate seed and mulch, establishing vegetation on the coarse tailings material that is often used for dam construction has been difficult. Additions of as little as ¼-½ inch of organic amendments has improved vegetation substantially.

All of the iron ore wastes noted above contain minerals associated with the iron ore and host rock. The materials can occur in a wide range of particle sizes based on the mining method and the geology/mineralogy of the ore deposit.

Overburden and waste rock are often stored or disposed of in unlined areas that are generally onsite. These dumps are typically unsaturated and provide a suitable environment for acid generation if sulphide minerals, oxygen, and water are present. Iron ore and raw coal piles may also be present at some abandoned operations (e.g. in the case of unplanned and sudden abandonment).

Aqueous effluent generation (major potential – coal, minor potential – iron ore)

Acid drainage remains the most significant aqueous effluent and one of the most intractable problems faced by the coal mining sector, a fact reflected by the ever-increasing volume of research published in conference proceedings, journals and books. There is a wide acceptance that acid drainage is the coal mining industry's greatest environmentally related technical challenge. As noted above, acid drainage results from the oxidation and subsequent leaching of pyrite and other metallic sulphides. Generation and migration of such drainage can persist for centuries and the volumes of contaminated water can be extremely high, particularly from sub-surface workings that drain large catchment areas (e.g. adits, tunnels and shafts).

The quantity and chemical composition of mine water generated at different mines will vary by site. Mine water will contain dissolved or suspended constituents similar to those found in the ore body and the surrounding area (rock volume). These may include traces of metals, but as noted above the quality of water from iron ore operations is generally better than that from coal operations where acid generating sulphides are typically present.

Although the iron ore industry uses large amounts of water, as noted above, acid drainage may not be a major issue at many iron ore operations, and physical impacts on water are more common (see above). For example, the Minnesota Department of Natural Resources (DNR) found that more than 95% of all leachate samples taken from an iron ore mine site between 1976 and 1980 had pH values between 6.0 and 8.5. However, values as low as 4.5 were reported along with increases in dissolved metal concentrations (Minnesota Department of Natural Resources, 1981). This may have been due to layers of pyrite-rich shale that are periodically disturbed during the extraction of the iron ore.

Individual level socio-economic impacts (major potential – coal and iron ore)

The socio-economic impacts of worker displacement caused by the closure or abandonment of any major productive unit are serious, and have been well documented by behavioural scientists. Research indicates that displaced workers subsequently tend to obtain jobs with less occupational status and income, have increased blood pressure and cholesterol levels, have increased alcohol and drug consumption, and are more likely to get divorced and abuse their spouse or child. A one-percent rise in unemployment has been linked to an increase of 4.1% in suicides, 5.7% in homicides, 1.9% in stress-related illness, and a 4.3% in admissions to mental hospitals (Kinicki et al 1997).

According to Haney and Shkaratan (2003) the problems of coping with closure or abandonment are made all the greater among mine workers in a number of societies because of the once privileged status and relatively high wages they enjoyed. In the same or other societies, they are made particularly problematic because of what has been described as the 'lonely mountain man culture', a prevailing masculine trait amid mine workers against self-disclosure and unwillingness to seek help. This is arguably compounded because of 'the increasing destruction and dissolution of a worker's culture, which eased unemployment through collective methods of coping' (Kieselbach 1987) resulting in unemployment today becoming a problem of individual concern.

A study by McKee and Bell (1986) found that male unemployment has a profound effect on the status of the spouse, with women becoming more likely to postpone a return to work or resign from their present employment activities. This was seen to be the result of a reinforced attitude toward traditional men and women's bread winning roles as a result of male redundancy. Given that a strongly male-dominated orientation has been observed in mine communities, such polarisation is likely to be particularly acute within mining areas, highlighting the importance of establishing support services that are able to address the direct effects of closure on women.

Ultimately, any account of the affects of mine closure on individuals has to be understood within the context of 'the social meanings actors attach to their actions, their definitions of their situation at particular points, and the ends which they are pursuing' (Bulmer 1975). With significant changes in the employment policies of mining companies, there has been a correspondent shift in the 'social meaning' individual employees attach to their work. One major change has been the recruitment of non-miners to the industry. For example, in northern Scandinavia, mining companies have provided jobs in areas that have undergone restructuring problems as a result of the mechanisation of forestry and the rationalisation of farming. In addition, there has been a growing trend of mining companies subcontracting work to smaller firms associated with transport or quarrying. Many mines now operate on a fly-in, fly-out basis. In Australia, open cast mining largely utilises the labour of workers from the city, who are temporarily based at the site in order to save enough money to leave and establish themselves in an alternative occupation (Neil 1992).

Community level socio-economic impacts (major potential – coal and iron ore)

A key impact of mine closure or abandonment on the community is out-migration. Haney and Shkaratan (2003) point out that this impact has both positive and negative consequences. It is negative in the sense that it dramatically affects the demographic balance and cohesion of the impacted community. Indeed, Macfarlane (2002) describes the local demographic effect that the closure of Uis tin mine in central Namibia had, which had previously directly supported the wages of 40% of the community. Following abandonment, the out migration of the predominantly young male labour force, left a high proportion (54.9%) of the entrenched population as economic dependents of a predominantly unskilled female adult population.

Out-migration can also be seen as positive however in the sense that it relieves pressure on the local labour market for those who choose to remain. For this reason, mining companies and governments have sometimes sought to actually support labour mobility following closure by subsidising transportation expenses. In Romania, for example, a law passed in 2003 entitled unemployed mine workers to a grant equal to two minimum wages if they accept a job more than 50km from their mining home.

Haney and Shkaratan (2003) suggest that in the restructuring of the coal industry in eastern Europe, the most common response to mine closure is one of retreat of the individual from the broader community, making the community as a whole more fragile and vulnerable, and reducing the capacity of the community to respond to company or civil society initiatives to assist it. The problems of loss of cohesion are compounded by the loss of what Haney and Shkaratan (ibid. 2003) refer to as 'community space', this includes the destruction or neglect of former mine supported infrastructure such as youth clubs, telephone systems and roads that allowed the individual and family to interact with others in the community and the world at large.

The response, and, therefore, potential socio-economic impacts of mine closure or abandonment on the community are likely to vary considerably depending on the settlement type and its social composition and cohesiveness. People in spin-off employment will be particularly significantly affected by the degree to which the local economy had become dependent on the mine or were given opportunities for developing capabilities relevant to alternative employment (Maude and Hugo 1992).

In addition, those affected by mine closure or abandonment cannot be treated as a generic case or a homogenous group. Mining settlements vary dramatically in the proportion of their labour force employed in mining, in the extent of employment and capacity to generate alternate employment, and in the extent of public sector employment and support. Some mine settlements are small and isolated, while others are major urban commercial centres. The economic diversity of mining communities is matched by variations in their social and demographic characteristics, as well as by a labour force that is more dynamic than ever. This diversity must be the starting-point for the evolution of community, state, union, and mining company measures for handling mine closures or mine abandonment (Warhurst et al. 1999).

10 Influence of Mining Method

It is important to remember that the biophysical and socio-economic impacts associated with coal and iron ore mining vary in type and magnitude between the two phases of production (extraction and processing) and post-abandonment impacts may also vary depending on where in the lifecycle of the mine the abandonment occurred. Impacts also vary according to the type of extraction method used (either surface or underground) and the type of processing methods employed, which in part determine the amount and chemical properties of the wastes produced. Other important factors include the size of the mine and the relative location of urban and rural communities.

The type of coal mining method has significant implications for post-abandonment impacts and biophysical regeneration priorities. There are two broad categories of coal – hard coal (which includes coking coal and other bituminous and anthracite coals) and brown coal (sub-bituminous and lignite coals). Coal has a wide range of moisture content (2–40%), sulphur content (0.2–8%), and ash content (5–40%). The depth, thickness, and configuration of coal seams determine how they are extracted. Surface processes, of which strip mining is one of the most cost-effective, are used to mine shallow, flat coal deposits. In strip-mining the removal of overburden and coal extraction proceeds in parallel strips along the face of the coal deposit, with the spoil being deposited behind the operation in the previously mined areas. Therefore, the open area at any one time is relatively low. In open pit mining, thick seams (tens of meters) are mined by traditional quarrying techniques. Underground mining is used for deep seams. Underground mining methods vary according to the site conditions, but all involve the removal of seams followed by more or less controlled subsidence of the overlying strata (World Bank 1998).

Iron ores are produced and consumed in huge quantities. Consequently, many iron ore extraction sites are correspondingly large. Ores are extracted almost exclusively using open pit methods, where the economic benefits of large-scale equipment can be maximised. However, this inevitably leaves a substantial and permanent void that can have a significant visual impact over an extended distance.

11 Identifying End-Use

In addition to the impact assessment the proposed post-abandonment land end-use is a key factor in determining the type of, and the degree of, regeneration, in addition to the specific regeneration activities (Wisconsin 2003). Total restoration is often perceived as the most appropriate objective without taking into account the feasibility of such a goal or the potential to generate other beneficial end uses. However, regulatory criteria such as 'restoring the area to pre-mining conditions' may be in conflict with the most sustainable or desirable development options in an area, and long-term land-use plans and regulations may need to be adjusted to allow new uses for the land. Appendix.28 (2002) presents the scenario of large flat areas created by waste storage facilities being used for wind farms to exemplify this point. While some parts of the mine site may return to their original use other parts the landform created by the mining infrastructure could be used to create renewable energy.

According to Appendix.28 (2002), the cost of regenerating abandoned mining areas may also be recovered over time if the area can be used for future commercial activity. For example some abandoned mine areas may become tourist sites with important spin-offs for the communities. There are a number of examples of this, including the Gold Reef City theme park in Johannesburg. In a study of the abandoned Uis mine in Namibia, Macfarlane (2002) describes how the National Government is working in collaboration with the mine land owner to investigate the marketing of the huge stark waste dump as a tourist attraction, while ex mine manager housing and land in the area has already been refurbished and sold on as retirement and holiday homes. Other land end-use possibilities include:

- Cropland.
- Pastureland.
- Forest.
- Residential.
- Industrial.
- Recreation.
- Fish and wildlife habitats (conservation and/or hunting).
- Developed water resources.
- Undeveloped or no current use.

A century of mining in West Virginia in the USA has left the state with numerous large underground pools of water. The quality of the water that is discharged from the underground mines is greatly influenced by the chemistry of the coal seam and local geology, and give west Virginia an advantage over other east coast states that rely on surface runoff as the water supply for trout production. Miller (2003) documents the work of the University of West Virginia, in cooperation with innovative mining companies, to stock game fish in mine discharge sites in the region, in an effort to definitively determine if commercial aquaculture could be used as a post mining land use, with encouraging results. Such fee fishing can be used as a market tool for better economic areas that have been depressed since the mines have shut down.

In some cases, however, options for ongoing land use will be limited due to economic, legal and technical constraints. An example provided by the Minerals Council of Australia (2002) is where deep voids remain with a surrounding area of instability, and it would not be appropriate to consider options that would attract people into the area. They conclude that the first priority must always be to protect the environment and public health and safety by using safe and responsible closure practices.

Ultimately decision over land end-use should be made in consultation with local communities to develop both capacity and confidence to identify which new economic activities (e.g. tourism, agriculture, light industry, small-scale mining, eco-tourism) will be the most appropriate targets for the regeneration process (Sweeting and Clark, 2000). Throughout this process there should be a focus on the preservation of cultural traditions and customary means of living, to ensure that these activities can continue post-regeneration as well as how reclaimed property fits into the broader physical environment. This could yield connections, for example, to planned or existing trails, recreational areas, wildlife management areas, or even wildlife migration corridors, especially if river or wetland complexes are in or adjacent to the mining site (Wisconsin 2003). After site impact and risk assessment and strategic assessment of the regional context, the preliminary analysis of planned end-use should then be re-examined to ensure it is both feasible and suitable in the wider context.

12 Financial Provisioning

Once end-use is decided, the necessary starting point for the implementation of regeneration measures is finance. However, the question of who funds regeneration of abandoned mines can be particularly problematic because the ‘polluter pay principle’ now applicable to most current mines is difficult to apply to abandoned mines since previous owners are often no longer viable companies, cannot be located, or are deceased, making cost recovery untenable. In addition, many sites are located in areas with other abandoned mines, making it uncertain who is responsible. An attempt to clarify the controversial issue of financial responsibility for both current and abandoned mines is made in Table 2, developed by Sassoon et al (2002):

Table 2: Possible allocation of financial responsibility for dealing with mining legacies.

Scenario	Responsibility
Ancient mine workings.	Regeneration with public funds.
Historic mine with no identifiable owner.	Regeneration with public funds.
Mine closed, and former operator can be identified but no longer owns the site.	Former owner could be liable or could be a public responsibility.
Mine closed, and former operator still owns the site.	Owner / operator is responsible for preventing damage to neighbouring property and controlling hazards.
Mine is still operating.	Owner / operator is responsible through an agreed closure plan.
Operating mine early in project life	Owner / operator is responsible through an agreed closure plan.
Permits granted but no operations have yet started.	Costs fully internalised to the extent current scientific and technical understandings permit.
Mine has not yet received necessary permits.	Costs fully internalised to the extent current scientific and technical understandings permit.

The costs of physical mine closure and regeneration vary greatly, and depend on the age, size, location, the type of mine, and the mineral extracted. As such costs need to be estimated on a case-by-case basis. However, preliminary research suggests that medium size open pit and underground mines operating in the past ten to fifteen years cost US$5-15 million to close and regenerate, while the closure and regeneration of open pit mines operating for over 35 years, can cost upward of US$50 million (World Bank and IFC 2002). The following concise approach by the California Mining Association (cit. Anderson 1999) in its Mining and Reclamation Act, Financial Assurance Guidelines provides a guide to calculating the costs of reclamation only:

'… Following the identification of broad reclamation categories, the component parts of these tasks should be identified. For example, revegetation may include seedbed preparation, seeding and fertilising, irrigation and weed control. Each of these subtasks should be estimated individually to simplify the process. Where grading of pit area is part of the reclamation plan, we recommend that cross-sections and maps of pit areas be used to justify grading quantities.

Identify the equipment necessary to complete the identified task.
Identify labour requirements
Identify materials to be used.
Define unit costs
Multiply the unit cost by production rate to determine the total cost for each cost item.
Add the cost of all cost items to find the total cost per category (e.g. equipment).
Add the total cost of all categories (i.e. equipment, labour, materials) to determine total cost of reclamation.
Add charges for supervision, profit and overhead, contingencies and mobilisation.'

Calculations must reflect the real and full costs of regeneration (Chamber of Minerals and Energy of Western Australia 1999). Experience suggests that closure and regeneration cost calculations tend to be underestimated, which Sassoon et al. (2002) attribute to the propensity for cost calculations to only take into account the costs of re-vegetation. Closure and regeneration costs in their fullest form should be composed of two parts: social costs and environmental costs, including rehabilitation and environmental liabilities. While they may be considered separately, social costs major neglected cost is the social costs of regeneration, relating, in the main, to redundancy payments, trust funds, transfer of social assets, and contributions to ward future maintenance and operations of social assets (World Bank and IFC 2002).

In order to avoid the difficulties of financing or attributing financial responsibility faced for abandoned mines, it is essential that costing and financial provisioning is made at the earliest stages of mine development, with initial cost estimates ideally prepared prior to mine opening, and updated on a regular basis (every five years for a 30 year mine; every two years for a ten year mine life) (World Bank and IFC 2002, Sassoon et al 2002). Financial provisioning is a mechanism to ensure that mines do not become abandoned and that there are sufficient funds available to close an operation and that closure and regeneration costs do not become a burden in later years of the mine's life when revenues can be diminished (ANZMEC 2000).

Cochilco (2002) identifies a variety of financial surety instruments ranging from irrevocable letters of credit to insurance policies and other guarantees. However, the two most popular mechanisms for providing financial assurance most frequently identified in the mining literature are surety bonds and trust funds. Miller (1999) presents a comprehensive review of surety bonds in various regulatory regimes, which he defines as 'guarantees issued by a bonding company, an insurance company, a bank, or other financial institution (the issuer is called the 'surety') which agrees to hold itself liable for acts of failures of a third party'. Although not widely used in the developing world, surety bonds provide an additional guarantee, over and above any traditional insurance policies, that funds will be available for regeneration in case a company abandons a site or goes bankrupt before regeneration processes complete.

According to Anderson (1999), because the sureties industry have a financial interest in the control of environmental degradation at mine sites, they can become a partner of the regulatory community, carrying out inspections and setting standards for environmental and social performance. Nevertheless, Allen et al (2001) note that differences in environmental and financial default risks between projects and between companies are generally not incorporated into performance bonds so it is unlikely that the optimal balance between mining and environmental and social protection is being achieved. One consequence of this is that bonds are frequently set too low. Da Rosa (1999) notes, for example, that when the owner of Summitville Gold Mine, Colorado declared bankruptcy in 1992, state regulators held a reclamation bond worth US$4.7 million, yet the US Environmental Protection Agency estimates that the full clean up of the site may total more than US$120 million. Allen et al (2001:17) conclude that:

'*Financial assurance systems that incorporate company specific information can more readily take into account many of the variations in risks associated with different mining projects. As a result, some combination of such mechanisms with the more traditional performance bond systems may lead society closer to outcomes that maximise the benefits from both mining and the environment'.*

Trust funds are another way to ensure that finance is available for mine regeneration. According to Anderson (1999) these are essentially indemnity agreements made by the government, using a portion of required company payments, or established using additional required or voluntary contributions from companies. These funds or assets are then held in trust by the regulator, the government, the bank, or similar financial institution. In the Philippines and in the state of Western Australia, companies are required to create a trust fund to cover social and environmental regeneration costs before they are awarded a mining lease (WWF 1999, Cochilco 2002). A number of foundations have been established in mining communities to provide long-term sustainability for some services. Examples of this include the Escondida Foundation in Antafongasta, Chile and the Rossing Foundation in Namibia (le Roux 2000). A similar approach is to establish a community trust fund that is protected against inflation. The income from the fund can allow communities to build their own capacity to manage their financial resources.

13 Specific Best Practice Regeneration Activities

In this following section specific best practice recommendations from the mining literature have been identified that relate both to measures to regenerate abandoned mines and to control and prevent operating mines from becoming abandoned mines. These measures are divided into categories, some of which relate solely to the treatment of issues arising from abandonment, while others relate to treatment of the regeneration activity itself as an aggravating factor (e.g. noise may be absent on the abandoned site, but present while biophysical regeneration is taking place). As noted in the introduction, for the purpose of this report coal and iron ore mining sites are treated collectively except where issues or best practice are sufficiently different to warrant individual analysis.

Appendix.28 (2002) notes that during the last ten years, a reasonable body of literature has been generated on the environmental aspects of post-mine regeneration and land use planning and implementation, but little on the other, economic and social sustainability dimensions, and, by extension, on integrated post-mine regeneration. Nevertheless, it is important to note that there is substantial crossover between many of these issues, and that the implementation of a best practice measure to address one issue may cause or aggravate other site-specific issues, or mean the most appropriate best practice measure for other issues will need to change or be adapted. The Department of Primary Industries, Water and Environment (1999) provides the following principles of best practice biophysical regeneration:

- Do not accumulate rubbish, disused plant, waste oil, other waste materials or general rubbish at any stage in the regeneration. These should be removed for recycling or appropriate disposal as soon as possible.
- On-site sewage treatment should not result in the pollution of surface or groundwater and should be designed and constructed to appropriate standards.
- Fuel, lubricants, coolant, waste oil and waste chemicals must be stored in an approved manner such as in drums or surface tanks with impervious bunds to contain spillage, and located away from operating areas, natural or engineered drainage pathways, waterways and areas prone to flooding. The volumes of such materials stored on-site should be minimised by appropriate purchase or waste disposal control protocols. Specifications for storage will depend on the quantity and class of the material being stored. Above ground storage tanks with impervious bunds should be used in preference to underground storage tanks, as these reduce the risk of groundwater contamination. Bunding should be regularly tested, along with the integrity of storage vessels. Bund walls may also be used to divert stormwater away from storage areas. Fluids released during machinery maintenance operations should not be spilled on the ground. This work should be undertaken on impervious pads with washdown sumps where the fluids can be captured and removed for appropriate disposal or recycling. Any hazardous materials stored or used should only be disposed of at designated sites.
- The final land use of the site will determine the final landform. Generally, the site should be shaped so as to blend in with the surrounding landscape.
- Minimisation of the total disturbed area at any one time during biophysical regeneration work is an important factor in reducing erosion potential and transfer of suspended solids to adjacent surface waters. The rate of run-off increases dramatically following vegetation removal, hence the total area exposed should be kept to a minimum. Poor drainage management can lead to damage or destruction of

rehabilitation efforts. Generally the best and most cost-effective erosion prevention method is the establishment of vegetation. While vegetation is becoming established in rehabilitated areas, it may be necessary to employ other erosion prevention techniques. It is generally wise to retain any existing drainage controls, such as contour banks, rock filters and cut-off drains, upslope of the area being rehabilitated, to slow down surface run-off. A rough surface will capture more water and allow rainfall to infiltrate rather than flow directly downhill. Deep ripping will improve water infiltration, again reducing the flow of eroding water over the surface.

- A cut-off drain or diversion bank above the excavation will help prevent water from entering the site and aggravating erosion problems. Cut-off drains should discharge into vegetated natural drainage pathways or into level, stable areas. Contour banks and contour drains can also be used to capture and slow water that would otherwise cause erosion. Access tracks and roads often have a major impact on water quality. Gradients should be controlled, drains well maintained, and regular cross drains or culverts installed to keep tracks clear of standing or flowing water.
- Where settling ponds already exist on a site, it may be beneficial to retain these in the long-term where possible to capture sediments not controlled by revegetation or preventative measures. These ponds will require periodic cleanouts to ensure they operate at maximum efficiency, and pond outlets and drain outlet points should also have erosion protection such as spillways to undisturbed natural drainage pathways, pond decant pipes, riprap outlets, straw bale barriers, flume or other forms of energy dissipaters. Care should be taken to avoid leaving any ‘up and down’ features on slopes, such as bulldozer tracks on resoiled or contoured areas, as these tend to channel run-off downhill and increase erosion.
- Construction and lining of ditches around the site boundary should be undertaken to reduce lateral movement of water from adjoining areas, if this is considered to be a significant source of on-site water.
- Construction of on-site water transfer system, minimising time during which water could be exposed to contaminants should be considered rather than relying on gravity flow. System should be designed to minimise uncontrolled movements of surface water, and should use one or more marshalling points to centrally control water movement, treatment and discharge. Central water storage areas should be lined to prevent movement of contaminants into groundwater.
- Cover systems (e.g. overburden/soil/vegetation) should be used to manage water flows over and through wastes and worked out areas.
- Water should be routed away from areas with potentially problematic minerals (e.g. soluble minerals, waste containing sulphides prone to oxidation metal release).
- Final cover of topsoil on mine backfill contributes to reducing the influx of oxygen and decreasing oxygen concentrations within the underlying mine spoil.
- A separate, sealed pipe system should be used for discharge of sewage wastewaters.
- During revegetation, the application of fertilizers should be controlled to prevent excessive dissolution and contamination of water with nitrates or phosphates.
- To prevent transfer of sediment to on-site water:
  - ➟ Expose the smallest possible area for the shortest possible time.
  - ➟ Limit volumes and speed of runoff.
  - ➟ Maintain protective vegetation.
  - ➟ Use scheduling to minimise the size of temporary stockpiles of materials (a potentially major source of sediments transfer).
  - ➟ Reclaim disturbed areas as quickly as possible.
  - ➟ Minimise slope gradients (in keeping with surrounding land).

14 Site Investigation Activities (relevant to coal and iron ore)

Although preliminary site investigations during the regeneration phase are unlikely to cause major biophysical impacts, a number of simple preventative and remedial 'housekeeping' measures are recommended to avoid residual issues. In particular these relate to the recovery of physical samples for analysis of water and land quality.

Preventative Measures

- Schedule operations during least sensitive periods (e.g. avoiding migration, nesting and mating seasons for relevant fauna).
- Minimise noise and dust when working near residential areas.
- Keep site clean and tidy and remove all rubbish.
- Identify and protect any rare or endangered fauna and flora.
- Avoid spreading any plant or animal disease or noxious weeds.
- Use existing tracks where possible and minimise unnecessary clearing of vegetation.
- If new tracks are necessary, placement should avoid areas of significant vegetation or where likely to stimulate erosion (e.g. steep slopes, banks of surface waters).
- All fuel, sewage and chemicals should be stored properly to avoid contamination.
- When contaminated land is suspected (e.g. site activities included those likely to cause contamination or spills/accidental releases are known to have occurred) care must be taken to avoid the transfer of contaminants to deeper strata and excavated materials should be treated and/or disposed of in a suitable landfill.
- Minimise risk of fire.
- Where vegetation has to be cleared, stockpile the topsoil (separately from the subsoil) and replace on disturbed areas (seeded or fertilised if required).
- Use hand cutting to clear vegetation.
- If machinery is necessary, be selective in using it.
- Do not burn brush and uprooted materials.
- Where vegetation and soil are removed, ensure proper separation and storage. Collect seed, rootstocks and brash for subsequent revegetation.
- Ensure saline or contaminated water and drill fluids are not discharged into the surrounding environment via sumps, controlled drainage etc.
- Make arrangements for periodic monitoring and assessment of remedial action.

Remedial Measures

- Although generally on a small-scale relative to the coal or iron ore mining operation that preceded it, ground investigation using boreholes and trenches can still potentially cause impacts on ground and surface waters. Drill holes should be capped or filled; excavations and trenches should be backfilled (or fenced if left open).
- Where necessary, boreholes should be grouted to prevent the migration of water, and backfilled as soon as they are no longer required to minimise the risk of contaminated surface water entering. Where they are required, lockable covers should be installed to prevent vandalism and the deliberate discharge of foreign materials into them.
- Pumped water should be monitored for contamination and treated as necessary. It should be discharged so as to avoid physical impacts (due to flow) or chemical impacts (due to contamination) in the receiving water body.

Sources of Best Practice Information

- Environment Australia (2000) *Best Practice in Site Investigation*.
- National River Authority (1992) 'Methodology for Monitoring and Sampling Groundwater'.

- British Standard Institute (1981) 'BS 5930 Code of Practice for Site Investigations'.
- Energy and Biodiversity Initiative (2003) 'Good Practice in the Prevention and Mitigation of Primary and Secondary Biodiversity Impacts'.

15 Landform Regeneration and Management (relevant to coal and iron ore)

The final landform must be safe, stable, non-erosive, and designed so that it will support the final agreed end-use. The type and extent of surveying needed to design a satisfactory landform depends on a number of factors (e.g. size and shape of the pit area being backfilled, number and topographical characteristics of surface waste dumps and waste disposal areas, and the extent of backfilling or landforming completed prior to abandonment). In strip mines and large open-pit mines, where back filling and rehabilitation have been carried out progressively, greater attention may be needed to survey any existing (incremental) pre-abandonment reshaping. Any post-abandonment work should form an integral part of the overall landform design for the site. This is particularly true of drainage design. In many cases the main biophysical concern regarding landform rehabilitation is major soil movement by erosion or landslides.

Basic design issues:

- Take topography, natural drainage and site run-off into account.
- Stockpiles and waste dumps should be levelled or re-graded, steep slopes battered back, and waste rock/overburden pushed into hollows or the toes of faces. The site should generally be left in a stable, free draining state that blends in with the surrounding area.
- For small open pits, calculate volume of the void and material available for fill to determine final topography (i.e. after backfilling will a depression or hill remain).
- Design should support a drainage scheme compatible with the surrounding land.
- Consider the need for proper slope profiles (i.e. convex in the upper 20-30 % and concave in the lower 70-80 %) during volume calculations and field surveying.
- Regardless of the area of spoil or waste rock dumps, achieving the planned landform relies on close cooperation between rehabilitation planner, surveyors, field supervisors and other relevant stakeholders.
- Field supervisors and other field staff must understand the importance of achieving correct slope angles and profiles and of producing the required channel gradients and cross-sections in watercourses and drains.
- Best practice means that all parameters must be in an acceptable range and that those parameters are maintained.
- Final stages of reshaping need control through regular surveying and checking, using elevation pegs and profile markers to guide the plant operators.
- Particular care should be taken in flat or low lying land to avoid poor drainage and waterlogging (e.g. in coastal heath and wetland areas, a difference in surface elevation of even a few centimetres can alter soil moisture regimes and make vegetative restoration difficult or impossible).
- Any new sites chosen for relocation of spoil or waste dumps must be acceptable from an environmental perspective and must not constrain future land use.
- Potential sites should be surveyed to determine whether any biophysical factors exist that might prevent the site being used (e.g. presence of rare and endangered species and communities of flora and fauna, drainage patterns and heritage sites).
- Create a stable final landform before topsoil spreading and revegetation commence.

Post-mining land capability and land use:

- Ensure visual and land use compatibility of rehabilitated abandoned land in designing a combination of landforms and revegetation processes.
- Sometimes, land disturbance caused by surface mining can be seen as an opportunity to return land to a more sustainable condition (than pre-mining conditions).
- If original capabilities are to be restored, the formation of appropriate slope angles and lengths are paramount.
- Topsoil selection and placement, plus the selection of plant species, should match the land capability that can be achieved based on slope angles formed in reshaping.

Visual requirements:

- Visually blend abandoned land with the surrounding undisturbed land.
- Generally slope angles within the range of natural slopes in the vicinity are most appropriate as this ensures visual compatibility and emulates slopes that are in harmony with local conditions of rainfall, soil type and vegetation cover and long term stability.
- In flat land, the production of similar slopes may not be possible. If compatible slopes cannot be achieved, steeper areas should be visually ‘softened’ by avoiding straight ridges and sharp changes of angle and tree planting to break skyline views.

Drainage and interface with surrounding land:

- Incorporate drainage and minimize disturbance to natural drainage patterns. Engineer slopes and drainage to reduce erosion. Design for storm conditions, ensure off-site natural runoff does not wash over site, and use perimeter drainage ditches.
- Deciding whether surface drainage should be directed towards the final void (e.g. in the conversion of voids to wetlands) or away from it. Drainage towards the void is easier to design, but may not always be appropriate. The most common reason for drainage towards the void is a desire to create water storage in the void for end-use.
- Low quality water should not be directed to remaining voids – runoff water quality should be the same as if the runoff is to be discharged to the general landscape.
- When draining runoff away from the final void:
  - ➟ Select suitable points around the perimeter of the spoil piles where runoff can be safely discharged into existing watercourses without overloading streams.
  - ➟ Ensure that the differential settlement of backfilled areas relative to undisturbed land does not reduce their elevation and cause water ponding.
  - ➟ When constructing new watercourses on backfilled material, use the lowest possible channel gradients in the downstream sections. Gradients should be progressively increased as construction moves upstream, mirroring stable natural landforms, where watercourses become progressively steeper upstream.
- The top surfaces of waste dumps can be either concave or convex in shape. Differential settlement can have an impact on the final shape of the top surface. Concave surfaces should never be used if a dump contains any materials that have the potential to produce pollutants over the long term (e.g. acid generating sulphides are present) or where there are doubts about the geotechnical stability of the material in high rainfall areas or during extended periods of heavy rainfall.
- A concave surface, used with chemically stable dumps, increases rainfall infiltration and increases temporary water storage to improve infiltration or to assist evaporation. Consequently, the reduction in runoff lowers the potential for erosion of the side slopes. This approach may be more applicable to iron ore dumps than to sulphide-bearing dumps associated with coal.

Slope angles and length

- Over geological time, the forces of erosion and deposition act on natural slopes until an angle is reached which, for a given soil type, is balanced with the catchment area, runoff volume and vegetative cover. This results in slopes that become progressively flatter towards the bottom, so runoff is kept at a roughly constant, non-erosive value.

- If new slopes are created with this proper profile, and with angles similar to surrounding land, then it can be assumed that the reshaped slopes will be stable, provided that suitably effective and permanent vegetation is established.
- Steep slopes of greater than about 30% will generally continue to erode unless expensive stabilisation measures or benching, to break the slope, are implemented.
- Drainage density on reshaped land should be equal to or greater than pre-mining density (if known or as estimated). Since backfilled areas are usually elevated as a result of swelling or bulking of the waste after excavation, it is safer to adopt a higher drainage density that reduces the volume of runoff any new watercourses must handle.
- Implement erosion and run-off control by dimpling, roughing, notching, cross-slope furrowing and by placing boulders to increase water retention and decrease erosion.

Sources of Best Practice Information

- Environment Australia (2000) 'Best Practice in Landform Design'.
- Environment Australia (2000) 'Best Practice in Rehabilitation and Revegetation'.

16 Drainage and Erosion Control (relevant to coal and iron ore)

Poor drainage management can lead to damage or destruction of existing environments and any restoration or rehabilitation efforts. Generally the best and most cost-effective erosion prevention method is good site design and the establishment of vegetation. Just as for during operation, the minimisation of the total disturbed area at any one time is an important factor in reducing erosion potential and transfer of suspended solids to adjacent surface waters.

While vegetation is becoming established in rehabilitated areas, it may be necessary to employ other erosion prevention techniques. It is generally wise to retain any existing drainage controls, such as contour banks, rock filters and cut-off drains, upslope of the area being rehabilitated, to slow down surface run-off. A rough surface will capture more water and allow rainfall to infiltrate rather than flow directly downhill. Deep ripping may improve water infiltration, again reducing the flow of eroding water over the surface.

During early rehabilitation work it is inevitable that newly formed surface will be exposed and very susceptible to erosion. Failure to provide adequate control increases the need for water treatment to remove suspended solids and loss of replaced topsoil. Soil erosion occurs when the energy of moving water or air exceeds the forces binding soil particles together. Sedimentation occurs when the water or airflow decreases to the point where it is no longer sufficient to hold the particles in suspension. Wind erosion may be insignificant in terms of actual soil loss, but gives rise to dust that may be a particular problem when an abandoned site is located near, and upwind of, residential areas. Damage caused by sandblasting to newly establishing vegetation may also be a problem during rehabilitation work. Water erosion can occur via raindrop splash or sheet erosion by flowing water. Best practice must address both air and water-related erosion mechanisms. However, it is notable that poorly designed and implemented drainage systems can give rise to greater erosion than if the area had been left.

The best protection against all forms of erosion is a dense cover of vegetation, which protects the soil surface against wind and raindrop impact. Therefore, satisfactory erosion control is generally achieved by managing (and in some regions fire control strategies) to maintain an adequate cover of vegetation. This may also involve control of grazing, removing feral animals and limiting access to prevent the formation of vehicle tracks (which may act as a 'starting point' for widespread loss of vegetation. Any areas of active erosion should be proactively treated with structural control works and re-vegetated.

Surface water management

- Divert water from undisturbed land around and away from disturbed areas and mine infrastructure, to minimise the volume of contaminated water needing treatment.
- Runoff from disturbed areas, including spoil, waste rock and overburden dumps, access roads and partially rehabilitated areas is likely to be contaminated with suspended solids and usually requires treatment by settlement or removal of fine silt and clay particles, before discharge or use. A system of drainage and diversion banks or channels should collect this in settlement dams.
- Overflow and seepage from tailings dams should be retained in a closed circuit and kept separate from other water categories, since it often contains chemicals, residual metals and potential toxins used in the processing plant. This water should be treated to remove solids, adjust pH, etc. as appropriate prior to discharge or use.

Erosion control

- For waste dumps with convex upper surfaces, a small bund (or graded bank) may be built at the interface of the top surface and the sideslope. Attention should be paid to the channel gradient so water does not pond in the channel.
- Erosion control works on waste dumps aim to maximise infiltration, and create an ideal situation for re-vegetating and restoration of the dump to its final land use. As noted, this does not apply to waste dumps containing unstable surface chemical materials.
- For waste dumps with concave top surfaces, the bund around the edge of the surface is not required unless it has been calculated that the storage area on the top surface is insufficient to hold the likely rainfall events. Best practice in most cases should provide a 'designed' (rather than random) point of discharge from the top surface of the waste dump down a suitable point on the outer slope.
- Contour cultivation is a common form of structural erosion control as it simultaneously provides a measure of erosion protection and cultivates the surface for sowing. However, the usefulness of contour cultivation alone is limited to slopes below about 8 %. On steeper slopes, the water-holding capacity of plough furrows becomes limited.
- Contour deep ripping or 'contour furrowing', in conjunction with contour cultivation, can provide a degree of erosion protection for a limited time. However, it should not be relied on as the sole structural treatment for slopes over about 18 % and for slope lengths greater than about 200 metres.
- Contour banks (a larger version of contour furrows, with a proportionately greater capacity to store runoff and/or drain it to some chosen discharge point) can be used to separate clean and contaminated runoff, to divert runoff away from disturbed areas, and to direct flow into settlement ponds and water supply dams. Contour banks come in three types: true contour (constructed precisely along the contour and designed to discharge at either or both ends); absorption banks (constructed along the contour with both ends turned uphill so that they pond a desired depth of water along their length) and graded or 'diversion' banks (constructed away from the true contour to drain water from one part of a slope to another).
- As slope angle increases, the erosion control value of even contour banks diminishes. Above a 26 % slope, they need to be so close together that they are of little benefit. Therefore, on very steep slopes, basin listing can be used to trap and promote infiltration of as much surface runoff as possible. It is important that basins do not overflow, as it will result in serious downslope erosion.
- Embankment and dams for the management of tailings should be constructed or maintained to avoid seepage, sliding and erosion using the concepts noted above.

Vegetative control of erosion

As noted above the best means of long-term erosion control is a dense, permanent vegetation cover. One of the objectives of revegetation work is to produce this dense cover as quickly as possible. Nevertheless, there is a period between final shaping and topsoiling and the establishment of vegetation, during which the surface is highly susceptible to erosion. Some erosion during this period is almost inevitable, although surrounding land should not be affected if a runoff and sediment collection scheme is in place. The period of susceptibility and degree of erosion can be reduced by the following appropriate management methods:

- Delay topsoiling and cultivation until as close as possible to anticipated sowing date.
- Sow when soil moisture and weather conditions are most favourable for the rapid germination and establishment of vegetation.
- The seed mixture should include at least one species that will grow quickly to provide early groundcover, even if that species will not form part of permanent vegetation.
- Cultivation, by whatever method, should be carried out on the contour. The use of a tined implement, such as a chisel plough, ripper or tool bar, will create small furrows to retard runoff and promote infiltration. After cultivation, traffic, particularly vertically across the slope, must be avoided due to its potential impact on erosion control.
- Cultivation should be deep enough to penetrate the underlying spoil material and should be completed in a single pass. The creation of a coarse seedbed promotes infiltration and resists the formation of a surface crust
- Mulching can act to retain moisture and resist erosion. Sewerage sludge has been used successfully as mulch where readily available and mechanically spread able.

Sources of Best Practice Information

- Environment Australia (2000) ‘Best Practice in Landform Design’.
- Environment Australia (2000) ‘Best Practice in Rehabilitation and Revegetation’.

17 Final Voids (relevant to coal and iron ore)

The existence, ultimate shape and size of a final void at the end of an open-cut mine’s abandonment depends on a range of factors. These include mining method, the resource size and extent, physical constraints (such as roads, railway lines, rivers, lease boundaries, etc.), resource extracted and partial backfilling activities. Therefore, a range of outcomes is possible at the time of abandonment, from situations where no significant void remains through to situations where all the resource has been extracted and no backfilling has been undertaken or possible due to lack of suitable backfill materials. Therefore, determining the end use for final voids is one of the most difficult aspects of regeneration due to the technical and economic costs associated with remediation related issues.

- If a void exists, options for beneficial uses should be identified through studies to assess economic and biophysical viability, as well as community needs and desires.
- In some cases it may be clear from the outset of regeneration work (or before even) that the void will have no beneficial use. Provided that the remainder of the mine site is satisfactorily rehabilitated, and the presence of the void is acceptable with respect to its biophysical impacts, the area occupied by the void itself is normally not significant in terms of land use and regional economic effects. Therefore, the first priority is to render the void safe from access by humans, livestock and wildlife. Factors to consider are:
    - In open cut coalmines, the instability of the highwall and low wall can induce failures or mass movement. It may be necessary to bench the highwall and reshape the low wall so that it has a stable slope angle.

- ➟ In open cut coalmines, it will be necessary to cover exposed coal seams with several meters of inert material to prevent ignition either from spontaneous combustion, bushfires or human interference.
- ➟ Barriers at a safe distance from the perimeter of the void must be used to discourage human access, or at least to warn of the void's existence. While fencing may be a suitable temporary measure, it is not reliable for long-term protection. It may be necessary to surround the void with a sizeable ditch or steep bund wall to prevent inadvertent vehicle access.
- ➟ Build a sump in a suitable location in the floor of the void, where seepage and surface runoff will drain and be ponded. The sump floor should be hard rock rather than backfilled material so that wildlife and livestock will not become bogged and trapped as the pond dries out.
- ➟ As much as possible, surface runoff from land surrounding the void should be diverted to prevent void flooding and potential development of instability.
- ➟ The void surroundings should be made as aesthetically pleasing as possible by appropriate revegetation and planting on low wall and adjacent to highwall.

- Possible end uses in remote areas generally fall into two categories, water storage or back filling with a waste material. However, there are alternative uses where voids have been turned into recreational facilities, educational resource and heritage sites, or have been further excavated as part of urban developments. While these options deserve careful consideration, they need investigation before a decision is taken:
  - ➟ Water storage: the main concern with using final voids for water storage is the quality of the stored water, especially during periods of drought when replenishment may be minimal and evaporation losses are high, leading to elevated levels of dissolved salts and potentially acidity. This is more likely to be an issue for coal-related voids than those associated with iron ore mining. Mine water from iron mines generally has a pH of seven or higher and presents fewer problems in terms of quality. The effects of the void on the surrounding groundwater regime, in terms of potential contamination and inflows/outflows must be investigated, both to assess contamination effects and also to determine the seepage losses. The likely water quality must be appropriate to the potential end-use. If modelling shows the water will be of low salinity and the void is reasonably close to productive farmland, irrigation uses are an option. Good quality water may also be suitable as a supply for nearby townships, provided the catchment is adequate and quality will not deteriorate in times of drought. The storage may also provide process water for other local mining operations and other industry, in which case high quality may be a lesser consideration. Using a void as a retention basin for major flood flows may considerably benefit a community, while at the same time providing useful water storage for use at other times. There may also be opportunities to create amenity uses, such as for water sports and fishing, though these are likely to be secondary to some other, more economically beneficial uses.
  - ➟ *Waste disposal* into final voids is another option, but one that must be approached with caution. The main factors to consider are the physical and chemical nature of the waste, its volume, the distance of the void from the source of the waste and transport requirements. The volume of a typical mine void is such that it can absorb an enormous quantity of urban garbage and fill material, but the potential leachate affects on the local water systems must be considered, and managed.
  - ➟ *Disposal of industrial and mining wastes* can be a realistic option and is probably the most common use for voids in many countries. The disposal of mill tailings, coal wash rejects and power station fly ash are all current uses for voids. The volume of these materials is usually sufficient to ensure that the void is filled within a reasonable time span. Moreover, filling with these materials achieves two benefits. The wastes are concentrated, which facilitates later recovery should they assume some economic value and the void, after back-filling and capping, can be

returned to productive land use. Ideally, only homogeneous waste material should be accepted and the material should be thoroughly tested for leaching characteristics and potential groundwater contamination before it is accepted. If the waste material is combustible or liable to spontaneous combustion, exposed seams in coalmine voids should be sealed with several metres of inert material, to prevent ignition. In India at present, abandoned mine pits are being backfilled with mine rejects. But as noted above, mine pits may have more productive uses than simply serving as mine waste repositories and a simple method involving indicators has been proposed for determining the best use of mine pits by TERI in its Tri-Sector Partnerships project.

Sources of Best Practice Information

- Environment Australia (2000) 'Best Practice in Landform Design'.

18 Underground and Dump Fires (only relevant to abandoned coal sites)

In open cut coal mining, large volumes of coal and carbonaceous material are exposed to oxygen in air. Once exposed, the materials oxidise and liberate heat. If the heat is not dissipated sufficiently rapidly, the temperature rises. This drives the oxidation and heat generation process at a faster rate and if unchecked, spontaneous combustion may result. The consequences of spontaneous combustion in spoil piles may be significant. For example, open fires and smouldering combustion can give rise to toxic fumes such as carbon monoxide, carbon dioxide, nitrogen dioxide and sulphur dioxide, as well as the 'tarry' emission products associated with incomplete coal combustion. Further consequences arise from the danger of fire spreading to surrounding land, the destabilisation of the landform with possible subsidence, landslides and the death of vegetation in the vicinity of the 'hot' spoil.

- Final landform design provides the fundamental solution in preventing self-heating in coal mine spoil. Planning spoil dumps and the ongoing post-regeneration monitoring and management of spoil prevents outbreaks of spontaneous combustion.
- All potential fuel sources should be identified during site investigations.
- Potential fuel sources should be appropriately placed during biophysical rehabilitation to reduce oxygen pathways in spoil piles (e.g. controlled placement of carbonaceous overburden and partings within 'pockets' of inert material).
- Cover all final surfaces with a 5 m layer of inert material.
- Compact final surfaces, as well as intermediate surfaces wherever possible.
- Spread out and track roll carbonaceous material to prevent heat build-up and oxygen ingress.
- Sealing hot spoil with a cover of clay is an effective technique to control heating.
- Grouting with inert material such as fly ash may be an alternate technique for fire control as this creates an *in-situ* barrier to air transport rather than a potentially unstable surface barrier (such as clay).
- Promote cooling by encouraging rainwater ponding.

19 Hydrologic Engineering (relevant to coal and iron ore)

Mining can impact the quantity and velocity of surface water flow by altering natural drainage patterns and the infiltration/runoff relationships in a watershed; discharging storm water and wastewater; impounding water; changing the character of gaining and losing stream reaches through mine dewatering; mining through stream channels and flood plains; and by diverting, re-routing, and channelizing streams. Importantly, many mining activities have the potential to alter the equilibrium balance between flow and sediment transport in streams (Johnson, 1997). Altering this equilibrium causes stream gradients, channel geometries, channel patterns, and stream banks to adjust to new equilibrium conditions that reflect new erosion and sediment transport characteristics (Johnson, 1997). Such changes can disrupt aquatic habitats both upstream and downstream of a mine. The creation of waste dumps, tailings impoundments, mine pits and other facilities that become permanent features of the post-mining landscape can cause fundamental changes in the physical characteristics of a watershed (O'Hearn, 1997). Modification of the surface catchment area and groundwater recharge may have parallel impacts on groundwater level and flows and the flow of surface watercourses. In extreme cases water features such as ponds, wetlands, and bogs may disappear as a result of changes in the flow and volume of groundwater and surface water. Although these may eventually be reinstated, even their temporary absence can have a severe impact on fauna and flora that are reliant upon them (Thompson *et al*, 1998).

- Collect and analyse appropriate meteorological and hydrological data (e.g. surface water discharge, precipitation, duration and intensity of storm events). In general, the longer the period of data, the more accurate seasonal variation predictions will be.
- Prepare water balances and create wastewater and storm water management plans.
- In the absence of appropriate historical information, establish stations to monitor stream discharge and meteorological conditions.
- Determine extent that the watershed physical variables control hydrological processes.
- Assess geology and soils lithology and mineralogy of rocks, soils, and alluvial deposits.
- Determine rock unit distribution; structural relations; fracture distribution and characteristics and surface-subsurface relationships.
- Undertake watershed delineation (e.g. flood plains, any special designation waters, stream gradients, channel morphology, channel pattern, stream flow/sediment transport relations, flood frequency & relationship between precipitation, infiltration and runoff.
- Undertake aquifer delineation (e.g. storage, direction of flow, gradient, permeability, transmissivity, water table elevation, recharge zones, springs and groundwater use).
- Surface waters such as rivers may need to be diverted potentially causing direct ecosystem impacts (e.g. on invertebrate communities living in the river sediments) and indirect impacts from the rechanneling of the water, including changes in flood risk and location. There may be substantial resistance to the relocation of surface waters by local communities and other stakeholders, and therefore this is an extremely high profile activity with substantial reputational risks in the event of subsequent problems.
- Changes to the overall flow of water within and from the catchment area are generally only significant when the area of the site being regenerated is significant compared to the overall catchment area, but in some cases this may require modification of the management plans for surface and groundwaters on-site and in the immediate vicinity.
- Previous removal of the unsaturated zone via extraction (e.g. overburden, coal or iron ore) can create direct routes between contaminating activities and groundwater/aquifers. Typically the unsaturated zone acts as a buffer, slowing the penetration of contaminants and reducing the risk of groundwater contamination through natural attenuation, adsorption and dilution processes (by which contaminants are removed or reduced in concentration before entering the saturated zone). This increases the significance of preventative measures as the treatment of contaminated groundwater and aquifers can be long-term, expensive and technically difficult.
- The removal of the unsaturated zone also increases the likelihood of groundwater fluctuations being more extreme, with recharge occurring at potentially problematic rates. This may lead to a higher frequency of flooding in groundwater-fed streams and possible problems with the saturation and destabilisation of natural and excavated slopes, leading to both environmental and operational problems.
- Although the unsaturated zone is not fully laden with water, it contains a significant portion of the overall water resource, and its removal can reduce the groundwater

storage capacity in the vicinity. Again, this is most likely to be an issue when the volume extracted is a significant part of the total volume of the catchment's unsaturated zone, or when several quarries operate within the same catchment area
- Excavation below the water table can lead to a loss of groundwater volume and quality during operation (although if the site is allowed to flood on closure the total storage volume will be significantly higher as void spaces in unbroken ground generally only comprise 5-20% of the total rock volume).
- Discharge of water into watercourses may cause damage to the banks and beds due to the increased water flow and velocity. This particularly the case for smaller watercourses receiving high volumes of water and should be avoided if necessary.
- Undertake predictive assessments of post-regeneration surface and underground water quality (e.g. based on results of geochemical testing and modelling).

Sources of Best Practice Information

- Environment Australia (2000) 'Best Practice in Landform Design'.
- United States Environmental Protection Agency (1999) 'EPA and Hard Rock Mining: a Source Book for Industry in the Northwest and Alaska, EPA 910-R-99'.

20 Visual Compatibility (relevant to coal and iron ore)

The visual impact of abandoned mining sites may be out of all proportion to the area they occupy. Improving the aesthetics of a site can relate to the improvement of the colour contrast of the site with surrounding countryside; undertaking significant changes in landform (as noted above); removing unsightly buildings; enhancing vegetation; removing high profile waste dumps; backfilling open pits; and restoring surface waters to their original routes.

- Ensure that the site and its surroundings are clean and tidy, well sign-posted and fenced. Measures should be taken as far as possible to ensure that site features that cannot be effectively addressed by way of removal or modification are screened to minimise their visual and landscape impact. The overall objective should be to ensure that the site blends with its immediate surroundings.
- Blend the site boundary fencing, entrance and general external appearance with the surrounding countryside.
- Place screening bunds to minimise the visual impact as necessary.
- Incorporate tree planting or the retention of forest or vegetation features into site regeneration to assist in screening.
- Design any screening, planting or grassed areas to be easily maintained.
- Consult the community on those aspects of the project that they find most aesthetically intrusive or unsightly.

Sources of Best Practice Information

- Environment Australia (2000) 'Best Practice in Landform Design'.
- Environment Australia (2000) 'Best Practice in Rehabilitation and Revegetation'.

21 Management of Non-Landscape Physical Features (relevant to coal and iron ore)

The first step in the regeneration process at many sites is likely to be the general clean up and securing of the area, in particular those issues not specifically addressed as part of landform management activities (e.g. lagoons, pits and openings that lead to sub-surface workings).

- Remove all fixed and mobile plant.
- Remove all temporary and permanent structures unless specifically identified as required in present or adapted form for the regeneration process.
- Level or landform noise control bunds and waste piles not specifically addressed in landform management plans.
- Remove and safely dispose of waste materials including hazardous materials.
- Break up and bury/remove concrete slabs.
- Rehabilitate roads, office sites, and hard standing areas not required in regeneration.
- Identify and remove any hazardous or contaminated materials, weeds or potentially problematic materials not required in subsequent regeneration activities.
- Plans for machinery hygiene during rehabilitation works should also be made with respect to controlling the transfer of weeds around the site, and off the site.
- Restrict access to required power supplies and remove non-essential power-related infrastructure (e.g. remove all elevated wires and poles and ground any buried wires).

Sources of Best Practice Information

- Bardos, R.P. 1993. Process constraints on innovative soil treatment technologies. *Land Contamination & Reclamation*, Vol. 1, No. 1, pp. 37-45.

22 Demolition (relevant to coal and iron ore)

Demolition generally involves destruction and removal of physical structures (e.g. buildings, plant) and will often be undertaken in tandem with making safe (see above). Demolition of contaminated surface buildings, foundations and plant can be a source of contamination (e.g. dispersion of contaminated solids, dusts, wastes and liquids from below or in buildings) and therefore this issue must be addressed in planning and implementing demolition work.

- Decontaminate buildings, equipment and storage areas if necessary prior to demolition.
- Dispose of surplus chemicals off site (e.g. chemicals to be recycled, returned to vendor, sold or disposed of in an approved landfill site as appropriate).
- Disassemble and remove all equipment and buildings, minimising the creation of dust and water pathways for the dispersion of contaminants.
- Break and bury or remove concrete foundations.
- Backfill excavations.
- Remove buried tanks.
- Remove means of access (e.g. roads and bridges) to appropriate areas of site in keeping with regeneration plan.

Sources of Best Practice Information

- Bardos, R.P. 1993. Process constraints on innovative soil treatment technologies. *Land Contamination & Reclamation*, Vol. 1, No. 1, pp. 37-45.

23 Protection of Infrastructure (relevant to coal and iron ore)

At many sites opportunities will exist to put existing infrastructure to beneficial use as part of the regeneration process. Both making safe and demolition activities should be undertaken bearing in mind the potential for re-use, adaptation and development of existing buildings, roads, power sources etc., to ensure the protection and enhancement of existing infrastructure as necessary to support sustainable local or regional activities. During making safe and demolition works it is also important to identify, protection and outline the restoration of important surface and sub-surface cultural assets. Although some cultural heritage assets may be identified during the initial site investigation, others may only be identified once making safe or demolition work has begun, and appropriate measures should be in place to accommodate such new finds.

24 Re-mining, Reprocessing and Utilisation of Mineral Waste (relevant to coal and iron ore)

Utilisation and reprocessing are two of possible *end-of-pipe* (or *remedial*) techniques for addressing the biophysical issues associated with waste disposal. The regeneration of abandoned mine sites represents a significant opportunity to develop new and innovative technologies for reprocessing of mine wastes and the development of policy and technical procedures to promote the utilisation of secondary wastes rather than primary resources where possible. Increasing constraints relating to the exploitation of primary resources have elevated some wastes into potential resources, and in a waste management 'hierarchy', utilisation and reprocessing are considered better environmental options than treatment or disposal (Harrison et al 2002, Macfarlane 2002).

Utilisation normally entails the use of the waste in an untreated form (although the physical form of the material may be adjusted): in the case of mineral industry wastes, utilisation may be more feasible following some kind of reprocessing (e.g. to remove or reduce the concentration of environmentally significant contaminants). Only those wastes that are sufficiently 'clean' should be used, particularly off-site as the major issue with waste utilisation is the potential to disperse environmentally harmful contaminants over a much wider spatial area. Generally, as the degree of contamination increases, so the potential for utilisation decreases. Another constraint to utilisation of wastes is their (generally) high place value, even if "clean" of contaminants. Transport costs beyond a relatively limited distance are likely in most cases to far exceed the saleable value of the waste itself, making on-site utilisation the most likely economic option.

The opportunity to reduce environmental hazards, improve the aesthetic appearance, enhance land use and decrease contaminating discharges may be made possible through remining (Skousen and Politan, 1995). The concept of re-mining and reprocessing to recover coal or iron ore may have great potential at older abandoned sites as the valuable content in the past was generally higher than those today and second, technology was less efficient (i.e. more valuable material was left in the ground or in the materials dumped as wastes). It has long been recognised that materials deposited in old waste heaps will often contain material with a current value that is near or greater than an economically viable minimum.

- Assess whether the amount of valuable material (i.e. coal or iron ore) contained in the spoil heap would be of economic interest (e.g. profitable, or of sufficient value to offset the cost of recovery and improved waste management).
- Reprocessing of wastes may not necessarily result in environmental improvement, for example in those cases where the residual waste (after reprocessing) still contains significant concentrations of other contaminants, such as sulphides (this is particularly true for coal, but may also be the case at abandoned iron ore operations). However, in many regulatory frameworks, reprocessing may be linked to safer disposal of the final waste (e.g. at an engineered disposal site) where this was not the case prior to reprocessing.
- Alternative approaches are also possible, including combined reprocessing-reclamation for historic sites. In the past, reprocessing was seen as an economic process (with the costs of recovery being lower, and coal or iron ore content higher, than for some virgin deposits). However, in light of the aims and objectives of sustainable development the

emphasis should now be split between economic, and environmental/social aspects. Retreatment should also encompass restoration and reclamation aspects, in order to reduce or remove the legacy of past mining activity. Liability issues may need to be addressed by state and federal government departments in order to catalyse this process.

- If re-mining is considered practical and of benefit to the regeneration process, it will be necessary to identify the elements of the mining operation that originally led to biophysical impacts and choose a re-mining method to address these (Hawkins, 1998).
- Predictive modelling should be used to determine the impact of remining on water quality as re-mining activity may have a negative impact (Hawkins, 1998).
- Consider the use of 'daylighting' (removing underground deposits via surface mining methods) if this will improve the quality of the environment (Hawkins, 1998).
- It may be possible to consider recovery of non-coal or iron ore by-products during re-mining and reprocessing (e.g. recovery of metals present as contaminants in acid drainage).

Waste Utilisation – On-site and Off-site

- Assess coal-derived ash and slag use in cement, geo-polymers, agriculture, building and other applications at a local or regional level; assess use of iron ore wastes as fill and construction materials.
- Assess utilisation of waste by characterising and identifying strategies for utilisation by other industrial processes that will form part of the overall regeneration strategy.
- Circumvent high place value of wastes by developing uses for the wastes on-site. This is already done to a large extent at most mining sites, and wastes are used in applications such as bunding, road building and maintenance and geotechnical support. However, the largest potential consumer of waste on-site is in the form of backfill, particularly for underground mines. Once again, however, the issue of contaminants and possible dispersion once the waste is in place arises, and it may be necessary to backfill the waste with Portland cement, pulverised fuel ash or other stabilising agents (e.g. soluble silicates). This however increases the cost and the normal cause of pursuing a policy of backfilling is problems with surface subsidence rather than a desire to improve resource utilisation.
- Backfill of wastes is widely used in shallow underground mining operations (e.g. coal, limestone). For example, the disposal of colliery spoil waste and pulverised fuel ash as a cheap backfill material (called "Rockpaste") via pumping into abandoned limestone mine workings to control surface subsidence has been undertaken in the UK's Midlands region (Braithewaite and Seago, 1990). A number of projects ranging in size from 20,000 tonnes to 800,000 tonnes have been undertaken, and in some cases the surface waste dumps have been removed completely. Trials are also planned with run-of-mine spoil from operational coalmines (rather than waste dumps).
- Waste materials may also find uses as substrates for revegetation and reclamation activities, but their physical and/or chemical characteristics may need modification in order to be suitable (e.g. the addition of organic matter, a source of plant nutrients, and a wider range of particle size in line with the appropriate soil type).
- Coal mining waste has also been used in the UK as bulk fill material in road building, rail embankments, and as in-fill. In some cases, the addition of other additives such as lime and bituminous binders has been used to improve the quality and suitability of the material for end-use (MES International, 1997), such as in reinforced earth structures.
- Other smaller volume options include the manufacture of bricks and blocks for local construction purposes and pelletising and firing of colliery spoil to produce materials for agricultural and hydroponics use or for use as an aggregate in lightweight concretes.

Sources of Best Practice Information

- A.K.M. Rainbow (ed.). 1990. *Reclamation, Treatment and Utilization of Coal Mining Wastes: Proceedings of the Third International Symposium*, Glasgow, 3-7 September 1990, pp. 544 pages, August 1990, A.A. Balkema, ISBN 9061911540.
- Cooperative Research Centre for Coal in Sustainable Development – *By-products and Waste research programme*.
- BGS 'Minerals from Waste' project.

25 Water Supply and Flooding (relevant to coal and iron ore)

It is essential to design the regeneration process to avoid the loss or reduction of water resources important to communities or agriculture, including adverse impacts on river flow, groundwater levels and drinking, cooking, irrigation and washing water supply.

- Consider existing needs for water in the area and the potential impact of regeneration.
- If dewatering of areas is undertaken during regeneration, consider measures to ensure that the lowering of water levels in adjoining land or water bodies is avoided.
- If the regeneration work increases water evaporation or reduces groundwater resources used for drinking consider preventative measures.
- If regeneration is likely to increase turbidity, pollution or other quality reductions that prevent water use by local people, identify preventative measures.

The flooding of sites can lead to significant release to the water environment and surrounding land of waste and contamination. Inappropriate biophysical regeneration may lead to land erosion or increased flood risk to adjoining land and communities:

- Implement a flood warning system as part of the regeneration process.
- Put in place measures to protect adjoining land uses from flood risk where this arises as a result of landform changes during the regeneration of the site.
- Address in site designs the minimisation of disturbance to riverbeds (e.g. avoid disturbance of riverbanks and prevent riverbank erosion).

Sources of Best Practice Information

Macfarlane, M. and Mitchell, P. 2003. *Scoping and Assessment of the Environmental and Social Impacts of River Mining in Jamaica*, Warwick Business School, University of Warwick.

26 Managing Sulphidic Wastes and Acidic Drainage (mainly relevant to coal)

Acid and metal contaminated drainage may occur as a result of sulphide oxidation in existing dumps and may be aggravated during landscaping, contouring and waste movement through increased exposure of un-reacted sulphides to oxygen and water. A number of established methods to prevent and treat acid drainage from sulphide-bearing waste, can be identified:

- *Capping and cover systems*: e.g. covering soil and drainage layer (coarse, inert material necessary) or low permeability liner (durable, but expensive)
- *Surface hardpan formation*: surface hardpans are a hybrid of capping and chemical treatment. Chemical (normally lime) is added in excess to the surface of the acid-generating waste. Chemical reactions cause the generation of a surface hardpan that reduces water and oxygen infiltration to the waste below. This approach may be more cost-effective than combined treatment and capping, but requires additional soil cover

(for revegetation) and is only applicable to areas where no major post-regeneration disturbances are anticipated (i.e. no vehicular traffic, excavation etc).
- *In-situ chemical treatment*: addition of a suitable (and preferably locally available) neutralising material that can raise the pH, slowing or preventing the acid generation process and neutralising existing or additional acidity. Appropriate add rates should be calculated from laboratory and pilot trials as a minimum and preferably from large-scale field trials that account for variations in the physical and chemical characteristics. Added materials should have minimal potential to cause water or soil impacts (e.g. they should contain no significant harmful metals as impurities). Suitable materials include lime ($Ca(OH)_2$), quicklime (CaO) and limestone ($CaCO_3$). Other materials have been tried, but cannot be considered generally applicable or indicative of good practice at anything but a site-specific level at present. In-situ chemical treatment may be used in combination with capping and cover systems.

Sources of Best Practice Information

- Skousen, J.G. and Ziemkiewicz, P.F. (eds) (1995) *Acid Mine Drainage Control and Treatment*.
- Mitchell, P (1999) Planning for Closure
- Mel Brown et al – Wetlands
- Environment Australia – Managing Sulphide Wastes

27 Prevention and Control of Acidic Drainage Generation & Migration (mainly relevant to coal)

There are two types of prevention and control, the first relates to the generation of acidic drainage, while the second relates to its subsequent migration. Both are inter-related in as much as certain approaches to preventing and controlling generation can reduce migration and *vice versa*, and therefore in some respects the division is an artificial one.

Methods proposed for the prevention and control of acid drainage generation include treatment of sulphide surfaces via the formation of inert surface ‘coatings’, the use of anti-bacterial agents (bactericides), the segregation of the principal acidic drainage-generating waste fraction and control of oxygen and/or water infiltration of the sulphide-bearing material. Currently, waste segregation and prevention or control of water/oxygen infiltration dominate, with the other methods having only limited application at full-scale. Certain approaches like inert surface coatings are unproven at present but worthy of further research.

In addition to the use of engineered covers, the most common approaches to preventing or controlling the migration of acidic drainage are the re-routing of water away from the source or the use of sub-surface seals and barriers to impede the movement of contaminated groundwater (British Columbia AMD Task Force, 1989; Filipek *et al*, 1996). The greater the control achieved, the smaller the volume of acidic drainage that is likely to require treatment. Just as waste minimisation is typically more cost-effective than waste management, prevention or minimisation of acidic drainage is generally considered a cheaper option than long-term treatment (Filipek *et al*, 1996).

- *Hydrophobic coatings*: research has assessed the use of fatty acid amines (Nyavor et al, 1996), which suppress bacterial activity and chemical oxidation. Treatment with the amine makes the pyrite highly hydrophobic and the pyrite surface consequently repels oxidising ions (i.e. $Fe3+$). It is, however, unclear whether the effect of the hydrophobicity prevents the bacteria from contacting the pyrite surface. Indeed there is considerable controversy as to whether bacterial contact is actually required for bacterially mediated oxidation to proceed since it is typically mediated through the generation of Fe^{3+}.

- *Inert coatings*: Georgopoulou et al (1996) examined the possibility of creating an iron phosphate coating on pyrrhotite to prevent oxidation. Using hydrogen peroxide to oxidise the pyrrhotite surface, then potassium orthophosphate to provide the phosphate for the coating and sodium acetate to buffer the pH, the researchers successfully formed a coherent iron phosphate coating on the pyrrhotite in small-scale column experiments. The resistance of the coating to oxidation was tested using hydrogen peroxide as the oxidising agent and was shown to be substantially better than control samples. Further research is necessary to detail the economic costs and technical constraints of larger-scale applications, but this approach does look promising, possibly as a means of treating segregated high-sulphide wastes prior to disposal. Other coating agents have also been suggested (e.g. humic acid, oxalic acid, sodium silicate) but remain unproven (Maki et al, 1995; Mitchell and Atkinson, 1995).

- *Bactericides*: are normally based on detergents that break down the greasy film at the surface of the bacterial cell wall. The film normally protects the bacteria from the surrounding acid environment and once it is removed, the bacteria cannot survive the acid conditions. Although bactericides can temporarily disrupt the activity of acidophilic bacteria such as Thiobacillus ferrooxidans and Thiobacillus thiooxidans (Filipek et al, 1996) if the bactericide is removed or becomes depleted, bacteria quickly repopulate the local environment. Slow-release formulations are commercially available that reduce acid generation up to 10 years. Ideally, this is long enough to establish stable soil and vegetative covers that prevent re-acidification (see Engineered covers, below). Bactericides have proven to be most effective in delaying or preventing acidification in highly pyritic acidic drainage sources (Kleinmann, 1997; Kleinmann, 1998). Alternative agents based on thiol-blocking agents have also been suggested for the inhibition of neutrophilic Thiobacillus species that are able to oxidise various sulphur compounds under neutral pH conditions (Stichbury et al, 1995).

- *Seals, grouting, interception trenches and sub-surface barriers*: sealing mine openings, adits, tunnels and adits can prevent the infiltration of water into, and the migration of ARD out of, underground workings. Preventing the movement of water through such workings can minimise sulphide oxidation even if the workings are flooded, as static water will quickly become anoxic as oxygen is consumed by chemical and biological reactions. Cementitious grouts can also be applied to prevent the infiltration of oxygenated water (Scheetz et al, 1995). One of the main concerns relating to the use of seals (other than cost) is that of sudden failure and the consequences of a sudden and massive acidic drainage release (e.g. the release of over 10 million gallons of highly contaminated acidic drainage into the Carnon River from Wheal Jane mine, Cornwall, UK in 1992 following the failure of the plug sealing Nangiles Adit). The risk of sudden failures in now being reduced by the fitting of relief valves to allow excess water to be drained off (and treated) during high flow periods (Mineral Policy Center, 1993), thereby controlling the pressure on the seal and surrounding host rock. Interception trenches have also been used to prevent the migration of acidic drainage. For example, in Montana at the Clark Fork site (containing four contiguous Superfund sites), the sites' owner Atlantic Richfield Corporation prepared an intercept trench to force the contaminated water to the surface where it could be treated by a passive system (see Mueller et al (1996) for details of the passive treatment system). This was possible due to the unusually shallow water table. At other sites, impermeable slurry walls have been used to impede flow of contaminated sub-surface water (Mineral Policy Centre 1993).

- *Engineered covers*: although waste dump geometry can be important in defining surface area exposure and air infiltration rates (Rastogi et al, 1995; USEPA, 1994), engineered covers are more effective at controlling oxygen and water infiltration and can be classified as oxygen barriers, oxygen consumers or reaction inhibitors (MEND, 1994). Soils and geofabrics (e.g. PVC and high density polyethylene) have been used to prevent and control water and oxygen infiltration into acidic drainage-generating wastes. Geofabrics are expensive, but if applied properly (i.e. to avoid punctures and rips) they are likely to have useful working lives in excess of 100 years (Filipek et al, 1996). Clays have often been used because of their minimal permeability and relatively low cost; however there is a danger that if the clay cover dries, deep cracks can occur, allowing the rapid ingress of water and oxygen. Engineered cover systems often include layers that promote lateral rather than vertical movement of water, a substrate for vegetation and protective layers between the geofabric (if used) and the waste to reduce the risk of physical damage. A free draining layer of closely sized coarse material is sometimes used to ensure that a capillary water column cannot form between the waste and overlying soil, thereby preventing the upward movement of contaminants. This coarse layer also helps to prevent the mixing of wastes and upper soil layers by burrowing animals, worms and other soil invertebrates. In general, the greater the number of layers, the greater the protection offered against acidic drainage, but the greater the cost of application (composite soil covers and plastic liners are generally the most expensive options) (MEND, 1995). Additional layers may include sewage sludge and composted municipal waste to promote oxygen consumption. One potential drawback to this approach has been highlighted by recent research, which has shown that ferric oxyhydroxides present in weathered tailings dissolve when in contact with organic acids originating in carbon-rich oxygen consuming covers (Ribet et al, 1995). The dissolution of the oxyhydroxide phase can result in the release of adsorbed or co-precipitated non-ferrous metals into the aqueous phase. Therefore, it is possible that in some cases, the use of oxygen-consuming layers may exacerbate the problem that they are designed to prevent (Ribet et al, 1995), and therefore the inclusion of carbon-rich oxygen consuming layers should be viewed with caution until further research has been conducted.

- *Sub-aqueous disposal*: sub-aqueous disposal can take the form of dumping into, and subsequent flooding of, open pits transfer to flooded subsurface workings, man-made and natural lakes or impoundments (Filipek et al, 1996), or into the marine environment (British Columbia AMD Task Force, 1989). Whichever option is chosen as the most practicable, cost-effective and environmentally-sound, the immediate disposal of reactive wastes underwater is preferable to storage (and oxidation) of the wastes prior to disposal. Storage can extend significantly the period of acid generation and metal release (St-Arnaud, 1994). Public and regulatory concerns over impacts on benthic life (due to close contact of such species with both the water and sediment phases) (MEND, 1993), and water quality may restrict disposal at natural lake and marine sites. Given its controversial nature and the lack of public and regulatory support (Fraser and Robertson, 1994), it is essential that scientific justification is made for this approach, possibly on a site-specific basis. Underground disposal and flooding requires a thorough understanding of local and regional hydrology and hydrogeology: tailings and waste rock should not be exposed to anything but stagnant (anoxic) water. Back filling into open pits or underground workings can also be expensive as it involves double handling of materials. Disposal in purpose-built constructed impoundments may be the most acceptable approach, although this implies that the capacity to plan ahead must be in place before this option is chosen: retrospective engineering of existing impoundments to allow adequate flooding may be prohibitively expensive. Disposal underwater in constructed sites is less of an issue (Price and Errington, 1994). However, in some cases, topographical constraints, the absence of an elevated water table and inappropriate climate can limit the application of flooded surface disposal sites. Despite these limitations, according to Filipek et al. (1996), sub-aqueous disposal has the greatest promise in controlling acidic drainage generation from solid wastes, as the diffusion rate of oxygen through water is four orders of magnitude less than in air. Therefore the supply of oxygen becomes the rate-limiting step in ARD generation, and significant generation ceases. However, research over a three-year period at the Noranda Technology Centre has shown that although water covers can reduce the rate of acid generation by 99.7% (Payant et al, 1995), the concentration of metals in the surface water can still exceed regulatory limits (Aubé et al, 1995). The inclusion of a biologically active organic layer on top of tailings has been suggested as a means of further reducing contact with oxygen and acting to confine metal contaminants. Oxygen infiltration of the tailings is controlled by its consumption in the organic layer (e.g. via conversion to carbon dioxide and water), while metal diffusion into the water can be further controlled by inoculation of the organic layer with sulphate reducing bacteria, capable of precipitating the metals as sulphides.

- *Hardpan formation*: hardpans normally form where the oxidation of pyrite and pyrrhotite leads to the cementation of mineral particles at the surface by a matrix of iron oxyhydrate. They may also form where solubilised ferrous and ferric iron reprecipitates at depth (typically at the interface between oxic and anoxic layers). Although natural hardpans are neither particularly chemically stable nor physically robust, it has been suggested that the deliberate construction of hardpans (using electrochemical methods) may help control infiltration by water and thus reduce or prevent the generation of acidic generation (Ahmed, 1995). However, this work has so far only proved possible under laboratory conditions.

- *Isolation, segregation and blending*: partitioning of wastes into sulphide-rich and sulphide-depleted fractions offers the chance to expand waste management options. In theory, the low-volume sulphide-rich fraction can be disposed of at a highly engineered disposal site or at least isolated as buried 'cells' within the bulk waste while the high volume sulphide-depleted fraction can be disposed of as an inert waste. However, the USEPA considers that the containment of sulphide-rich fractions may pose considerable engineering challenges (USEPA, 1994). Pre-treatment prior to disposal may be required (e.g. surface coating or co-disposal with neutralising agents). Blending of acid-generating and non-acid generating wastes can also be used to prevent or control ARD. However, as the latter is often exempt from permitting due to its inert nature, blending can sometimes result in the permitting of a much larger volume. This approach may, therefore, be environmentally attractive, but constrained by operator's reticence to extend or further complicate the permitting process.

Sources of Best Practice Information

- USEPA (U.S. Environmental Protection Agency). 1994. Innovative Methods of Managing Environmental Releases at Mine Sites, US Environmental Protection Agency, Office of Solid Waste, Special Wastes Branch (Washington, D.C.), OSW Doc. 530-R-94-012, April, 1994.

28 Treatment of Acidic Drainage (mainly relevant to coal mining)

While the aim of best practice must be to prevent or control the generation of acidic drainage generation and migration at *all* sites using techniques such as those outlined above, in reality there will always be cases where remedial treatment is required either as a temporary measure or on a more permanent basis. However, best practice should in theory reduce the significance attached to treatment as a component part of the closure and post-closure process.

There are a number of overlapping approaches to the treatment of acidic drainage, which are nominally categorised here as (a) active; (b) passive and (c) active-passive hybrid systems. Typically, active treatment systems require less land than passive systems, but have higher operational and chemical costs. Capital costs *may* be lower than for passive systems, although this is not always true. The use of neutralising reagents is the principal active treatment method, and lime (calcium oxide or hydroxide) is the most commonly deployed chemical. Passive methods use chemical and biological processes to reduce dissolved metal concentrations and neutralise acidity. Constructed wetlands are now the principal passive treatment method. Innovative active-passive hybrid techniques are being developed in order to incorporate the best features of both, while minimising operational and performance limitations. Examples include microbial mat systems and bioreactors.

Active treatment systems - liming and related technologies

In conventional lime treatment, there are five basic steps following collection of the ARD: equalisation of the treatment plant feed to minimise variations in water quality; aeration to oxidise Fe^{2+} to the less soluble Fe^{3+} (normally using air, but hydrogen peroxide, ozone and biological oxidation have also been investigated (Rao *et al*, 1995); neutralisation to increase pH to precipitate metals as hydroxides; sedimentation to separate water and solids, often involving the use of chemical coagulants and flocculants and finally sludge disposal. Combining certain steps can make financial savings. For example, the US Bureau of Mines In-Line System aerates and neutralises water simultaneously (Ackman and Kleinmann, 1991), reducing operating costs particularly when acidic drainage has high oxygen demand.

Although the most commonly used neutralising agent is hydrated lime ($Ca(OH)_2$), other agents that have been applied (normally in the treatment of low volumes of water) include ammonia, magnesium hydroxide, soda ash, caustic soda and limestone. A small number of proprietary reagents are also available, which normally compete with standard reagents on environmental performance and/or direct cost. Unfortunately, few higher environmental performance proprietary reagents are currently being used on a commercial basis and liming continues to dominate, based on its relatively low price and wide availability.

Although the cost of lime varies depending on volume bought, transport costs and other site-specific contract details between user and supplier, it is normally considered the most cost-effective technique where prevention or control has failed, particularly where an immediate response is required. Lime is normally introduced into the system as 5-20% (by weight) water-based slurry, although it is sometimes applied as a dry powder when the water volume requiring treatment is low. Its addition consumes acidity, forming water and insoluble calcium sulphate (if the sulphate concentration is high), and causes the precipitation of dissolved metals. The precipitate may then be settled or otherwise separated from the ‘clean’ water.

Iron and other metals may precipitate as hydroxides, basic sulphates or other compounds depending on the variety and relative concentration of anions and cations initially present in the aqueous phase. The stability of such precipitates in acid and alkaline environments varies considerably. Other metals such as aluminium, copper and zinc may precipitate as hydroxides. However, more complex species may also form, depending on the speciation and relative concentration of anions and cations. For example, arsenic (which has oxyanionic chemistry) may precipitate as a variety of ferric arsenate species, each having a different solubility. The precipitated sludge arising from liming operations should not, therefore, be considered a simple hydroxide precipitate, but a complex mixture of chemical species, for which the long-term stability may be extremely difficult to predict.

According to Kuyucak (1995) there are a number of factors that can affect the efficiency of treatment and the nature of the sludge produced, including:

- Rate of neutralisation (e.g. high rate result in gelatinous and voluminous sludges).
- Aeration and the oxidation of ferrous iron - ferrous hydroxide is soluble over a broader pH range than ferric hydroxide, and therefore aeration is often employed to ensure iron is present in the ferric form prior to precipitation. However, the ratio of ferrous to ferric iron can also influence the sludge density, with the highest densities being achieved for high ferrous iron waters.
- Mixing rate of lime and ARD - rapid mixing (e.g. in high shear mixers) can detrimentally affect sludge density.
- Sludge recycling – sludge recycling has been shown to improve sludge density and settling characteristics while reducing lime consumption (see *High Density Solids* and *NTC* processes, below).

In order to compare liming with some of the alternative approaches, the benefits and drawbacks need to be examined. The benefits include:

- Plant occupies a limited amount of space (although large areas may be required for sludge settling and disposal).
- Unexpected variations in water quality and flow can be accommodated by relatively easy adjustment of the operating parameters.
- Treatment is largely unaffected by temperature, and efficiency in winter is maintained.
- Effective in the treatment of highly acidic waters.
- A proven technology - mechanisms of metal removal and acid neutralisation are well documented and understood.

The drawbacks include:

- Equipment maintenance is relatively high due to the periodic build-up of calcium carbonate and calcium sulphate ‘scale’.
- High pH is required to remove metals such as manganese. However, based on the author’s own experience, certain metal hydroxides (e.g. $Al(OH)_3$) may redissolve in the highly alkaline solutions required to complete metal precipitation, necessitating a multi-stage treatment to reduce all metals to acceptable concentrations.
- Sludges derived from the liming of acidic drainage are chemically unstable and will partially redissolve if exposed to a sufficiently acidic (or in some cases, alkaline) environment. Therefore, the chemical nature of the sludge poses a possible long-term, post-disposal hazard. For example, in the USA, due to this fact, some sludge is treated as hazardous wastes, dramatically increasing the cost of disposal.
- Sludges are comprised of fine particles, and normally have a low solids content. Consequently the sludges are difficult and expensive to handle, and require some form of dewatering prior to disposal. Settling lagoons (the cheapest dewatering option) sterilise large land areas, while mechanical dewatering can be prohibitively expensive.
- The sludges normally have no commercial value, and reprocessing to extract the metal content is uneconomic with existing technologies due to the large excesses of lime that are often used during treatment to ensure complete precipitation.

The long-term disposal of liming-derived sludges and liabilities associated with the disposal site are probably the principal concerns of operators using this method, particularly in regulatory regimes that allow retrospective prosecution (e.g. the USA). Landfill is almost always prohibitively expensive, unless the site is owned by the operator and located near or on the mine site. The alternatives, such as on-site reclamation (including stabilisation, isolation and/or capping) are also likely to incur major engineering costs. As on-site disposal represents a long-term liability for the operator, the engineering standards for site reclamation will be extremely demanding, further elevating the cost. Some researchers have proposed underground (deep mine) disposal of liming-derived sludge. However, it is currently accepted that the long-term environmental impacts of this disposal scenario have not yet been properly assessed and that further research is required.

To address some of these drawbacks, a number of refinements to standard liming treatments have been developed in recent years. Two such examples include the High Density Sludge process and the patented NTC process developed at the Noranda Technology Centre and these are being applied increasingly within the industry (see cited references below for examples).

High Density Sludge (HDS) process

The HDS process produces a more compact and higher density sludge than standard liming treatment (<2% solids), for example, 10-30% solids, rising to 40-50% with time in the impoundment area (Murdock *et al*, 1995). Treatment is carried out in aerated reactors and part of the settled sludge is recycled to the beginning of the process, where it is mixed with the lime slurry. The sludge acts as an adsorbent for hydroxide anions, which are then gradually re-released into the untreated ARD. This prevents the rapid neutralisation of ARD (which can lead to a voluminous, gelatinous precipitate with low solids content and poor settling characteristics) and produces a denser sludge with improved settling performance (Kuyucak, 1995). Capital and operating costs of the HDS process were compared with those of precipitation plus centrifugation or filtration, biochemical extraction and sulphate reducing bacteria at Wheal Jane (Cambridge, 1996). Capital costs varied from £25 million for biochemical extraction down to £4.4 million for precipitation with either centrifugation or filtration. Operating costs ranged from £2 million per year for biochemical extraction down to £0.64 million per year for the HDS process. Given that the latter produced a sludge with a solids content of 45% (compared to 25-30% for the other treatments), this was the preferred choice at the site despite the slightly higher capital cost.

Passive treatment systems - constructed wetlands

In general terms wetlands can be described as areas flooded or saturated by surface water or groundwater often or long enough to support those types of vegetation and aquatic life that have specifically adapted to saturated soil conditions. Constructed or engineered wetlands attempt to duplicate natural systems and use chemical and biological processes to reduce dissolved metal concentrations and neutralise acidity. Compared with conventional active chemical treatment (e.g. liming), passive methods generally require greater land area, but use cheaper materials (sometimes waste products) to support the chemical and biological processes, and require less operational attention and maintenance. However, they are not "walk-away" solutions but, theoretically, low maintenance, low energy systems (Cambridge, 1996). Passive systems encompass a number of discrete unit processes, typically in the following sequence (NRA, 1994):

- *Anoxic ponds* reduce the dissolved oxygen in the water and marginally increase alkalinity. Reducing the oxygen content reduces deposition of metals within anoxic limestone drains (the next treatment process). However, anoxic ponds are not yet considered a proven technology. Generally these ponds are engineered to drain downward, forcing water to flow through an organic-rich (oxygen consuming) layer.
- *Anoxic limestone drains* consist of an enclosed layer of limestone that adds alkalinity and thereby reduces the size of aerobic cells (the next treatment process). These drains are typically placed to intercept acidic, anoxic ground water. Acidic drainage that contains significant dissolved oxygen must first be deoxygenated.
- *Aerobic cells* are planted with suitable wetland plant species (such as broad-leaved cattail (*Typha latifolia*)). The water flows across the surface of the cell, promoting contact with oxygen in the air. The cells remove iron and aluminium as hydroxides. Arsenic and a fraction of the other dissolved metals are removed by adsorption onto the surface of iron hydroxide particles. Plants aerate the substrate and produce alkalinity by

passing carbon dioxide through the root system. However, the cells are net producers of acidity as sulphuric acid is produced as a by-product of iron precipitation.

- *Anaerobic cells* are organic matter-rich, and may or may not be planted. Planting allows the regeneration of the organic matter as the plants die and decompose, and helps filter suspended solids (Filipek *et al*, 1996). Water flows vertically down through the organic matter, minimising contact between the water and oxygen in the air. Bacteria in the organic substrate produce hydrogen sulphide from sulphates, which then reacts with dissolved metals to form insoluble metal sulphide precipitates. The cells remove cadmium, zinc, copper, some iron and sulphate, and produce net alkalinity.
- *Rock filters* provide a large surface area on which algae and manganese-oxidising bacteria grow. The algae generate a high pH that allows manganese to be removed from the water. Algae also require manganese as a micronutrient, and can accumulate large amounts (up to 5.6% by weight based on dry tissue matter). Manganese removal is only significant at pH > 6 and low iron concentrations, so these filters are generally only effective in the later stages of treatment.

Benefits

- Capital costs may be relatively low if the volume of water to be treated is low.
- Operational and maintenance costs appear to be relatively low.
- Generally self-maintaining and requires little or no operator supervision.
- Anaerobic cells may be able to utilise waste organic materials (such as composted sewage sludge, farmyard manure and sawdust) as suitable substrates, thus mitigating one waste problem in the treatment of another.
- Wetlands provide a wildlife habitat and replace a valuable natural resource that has been significantly damaged by past human activity

Drawbacks

- Wetlands can require large areas of flat or gently sloping land (measured in tens of hectares). Even if suitable land is available, purchase for conversion to wetland may be prohibitively expensive.
- As a result of the reliance on biological processes, treatment during winter month's declines due to reduced bacterial activity at lower temperatures (Filipek *et al*, 1996). Unfortunately, this often coincides with periods of peak flow of contaminated water.
- Long periods are required for system equilibrium to be reached (possibly measured in decades) due to the biological nature of the treatment system. Consequently, the long-term efficacy of wetlands, particularly in the treatment of acidic drainage from metal mining operations, remains uncertain since few systems have yet reached equilibrium.
- Aerobic cells are more efficient at removing metals from less acidic waters and can be prone to freezing during winter months.
- Anoxic ponds as a pre-treatment step for anoxic limestone drains are a recent development and relatively unproven.
- When acidic water containing any ferric iron or aluminium contacts limestone in the anoxic drain, metal hydroxide precipitates form, 'armouring' the limestone (Filipek *et al*, 1996), thereby reducing the generation of further alkalinity and impeding flow through the drain. Any decrease in alkalinity produced by the anoxic limestone drain will increase the required area of aerobic cells.
- Passive treatment systems cannot be expected to perform indefinitely. In the long-term, the conditions that facilitate treatment will be compromised.
- The impact of metal-contaminated substrates on the food chain is largely unknown.
- Unexpected or unpredictable variations in water quality and flow may cause the metal removal capability of the wetland to be exceeded, causing the release of untreated water or introducing the need for additional back-up treatment systems. Flow-through of untreated water may have a detrimental impact on established plants in the latter stages of the wetland treatment process.

- The percentage of carbon available for actual use may only be a small fraction of the total present in the organic substrate. This would indicate that substrates would have to be replaced more frequently than previous estimates (Eger and Wagner, 1995), and that periodic maintenance will also be essential (Eger *et* al, 1994).

Many of the concerns relating to liming-derived sludges also apply to engineered wetland treatments. Two principal questions have yet to be answered: (a) is the substrate, or will the substrate become, a hazardous waste, and (b) what are the options for disposal or use of the spent substrate? Until these questions are answered, constructed wetlands must be considered a potential future liability in much the same way as liming sludge disposal sites.

Once the operational capacity of the wetland treatment system has been reached, not only do the problems of substrate treatment and/or disposal have to be addressed, but also the costs of reinstatement. In early research on constructed wetlands, it was assumed that they would be capable of working indefinitely. Estimates for the working life have since been revised numerous times, and the average now quoted is around 25 years. Consequently, multiple phases of capital expenditure may be expected if acidic drainage treatment is required for a longer period. This might dramatically affect the economic viability of wetlands in many cases, in particular where the volume of water to be treated (and hence size of wetland required) is large. Taking into account these points, constructed wetlands may be more useful for the treatment of low, long-term flows containing low concentrations of contaminants (Gusek and Wildeman, 1995), rather than high volume, highly contaminated acidic drainage. The more extreme cases may be better treated using active-passive hybrid systems or, in some cases, represent the opportunity to attempt resource recovery (e.g. metals, metal salts and other by-products).

Passive in-situ treatment systems

Porous reactive walls have been proposed as a means of treating sub-surface acidic drainage *in-situ* (Blowes *et al*, 1995; Waybrant *et al*, 1995). By excavating a portion of the aquifer body ahead of the contaminated plume and replacing it with a permeable reactive mixture, the acidic drainage can be treated *in-situ*. It has been suggested that the reactive mixture should be based on organic carbon to promote the action of sulphate-reducing bacteria and the consequent precipitation of metal sulphides (c.f.: *Bioreactors*, below). This approach has only been attempted at a limited scale, although the preliminary results appear promising in terms of both economic and technical performance (Blowes *et al*, 1995).

The use of sulphate reducing bacteria in open pits or underground workings has also been suggested as a means of treating acidic drainage *in-situ* (Kuyucak and St-Germain, 1994). This approach might be suitable for low-load scenarios, where a suitable organic substrate for bacterial growth is locally and cheaply available. However, efficiency might be compromised by a single addition of substrate if the substrate is so deep that mass-transfer is detrimentally affected. The operational temperature at depth is also an issue, as this will influence bacterial activity (c.f. performance of constructed wetlands during colder winter months).

Active-passive hybrid systems

Hybrid systems often use biological processes to neutralise acidity and remove dissolved metals from acidic drainage, but normally in purpose-built reactors rather than in natural system analogues. Current examples include microbial mats and bioreactors based on sulphate reducing and other bacteria:

- Microbial mats: Microbial mats are a heterotrophic and autotrophic bacterial community dominated by cyanobacteria and held together by the slimy secretions of various microbial groups (Bender et al, 1995). The mats are tolerant of high levels of toxic metals, and are capable of rapidly removing metals from solution via a number of processes, including the release of metal flocculating polymers. Various oxidative, reductive and precipitative reactions occur through the mat profile, which displays a steep redox gradient (passing from an oxic to anoxic environment). Based on small-scale field trials, the mats are durable, low cost and can be adapted to include specific microbial communities. This opens up the possibility of development of mats for specific applications (e.g. depending on type of effluent and suite of metals present). However, further research to scale-up the processes is required.

- Bioreactors and other biologically-based treatments: Bioreactors have been suggested as alternatives to constructed wetlands. Johnson (1995) analysed the possible applications of iron and sulphate reducing bacteria in the treatment of ARD using a series of bioreactors that would simulate anaerobic wetland cells. In the first stage, iron would be reduced from ferric to ferrous state, and in the second, metals would be precipitated as sulphides. By reducing iron to its ferrous form, the freshly precipitated sulphides are protected from the oxidising power of ferric iron. This approach is at a 'concept' stage and requires fundamental research to determine such basic parameters as the retention time required in the bioreactors and to identify suitable bacterial strains. Another approach is to produce the hydrogen sulphide (H_2S) in a bioreactor that is isolated from the ARD. Pilot- and bench-scale tests in Canada (Rao *et al*, 1994; Rowley et al, 1994) and the U.S. (Hammack, 1994) have been very encouraging. Depending on the water quality, it appears possible to produce high-grade sulphide concentrates that, when shipped to a smelter, can offset the operating costs of a water treatment plant. Other advantages are that (a) potentially toxic metals are removed separately from the non-toxic metal waste (e.g. aluminium, iron and manganese), greatly decreasing sludge disposal costs and (b) sulphate concentrations are significantly reduced. Field tests are in progress in Utah, where contaminated ground water is being treated (de Vegt, 1997) and are planned for the Berkeley Pit Superfund site in Montana. A similar dual biological-chemical system ("Biosulphide") has been piloted at the Britannia Mine (Vancouver, Canada) by NTBC Research Corporation (Richmond, Canada). Treated water is used as a source of sulphate for the bioreactor, where H_2S is produced. The hydrogen sulphide is then used to precipitate metals in the chemical circuit (Rowley et al, 1994; Rowley et al, 1993). Pilot trials indicate that the capital costs of the system are less than for an equivalent liming plant, and that an operating profit would arise from the sale of zinc and copper sulphide concentrates (at this particular site). Other companies have also been involved in extensive research on similar applications of biological systems (e.g. Noranda Technology Centre) (Kuyucak and St-Germain, 1994a). Bacteria and fungi have been used for the direct biosorption of metals. This is defined as uptake by biomass (living or dead) via physico-chemical processes such as adsorption and ion exchange (Gadd and White, 1993). Fixed (immobilised) biomass can compare favourably with synthetic ion exchange resins in terms of loading capacity, selectivity and re-usability. Fixed metals can be concentrated via elution (typically with a mineral acid) and recovered by standard downstream processes. However, currently available fixed biomass systems are unlikely to be capable of dealing with high volume ARD flows. Fixed biofilms (e.g. rotating disc contactors) probably offer greater opportunities in terms of high volume throughputs (e.g. the biological treatment process applied at Homestake Mine to degrade cyanide, thiocyanate, ammonia and biosorb metals simultaneously) (Gadd and White, 1993).

Sources of Best Practice Information

- Skousen, J.G. and Ziemkiewicz, P.F. (eds) (1995) *Acid Mine Drainage Control and Treatment*.
- Brown, M., Barley, B. and Wood, H (2002) 'Minewater Treatment. Technology, Application and Policy, IWA Publishing, London, ISBN: 184339 004 3, 453 pp.

29 General Water Quality Protection (relevant to coal and iron ore)

General water quality protection may include the prevention and treatment of a range of physical and chemical contaminants in addition to that arising from the generation of acidic drainage (see above), for example: process chemicals, elements and chemicals present in coal wastes such as salinity, spills or leakage of other materials (e.g. mineral oil lubricants, petroleum and derivatives, cleaning agents). It is important to avoid disturbing contaminated materials unless a planned response to release of chemicals is in place, and known containers of contaminants, such as storage containers, should normally be emptied prior to removal

Table 3 summarises the variety of sources that may require management and where action to prevent or limit contamination may be necessary. The potential to limit the significance of specific sources (in terms of volume of water) is also shown, although this is largely site-specific and difficult to generalize across different abandoned sites.

Table 3: Water sources and the potential to limit on-site volumes

Source	Potential to limit contamination volume available
Rainfall	Minimal – local climate will largely dictate total volume of rain falling on-site
Groundwater	Limited – may be able to depress through pumping
Surface waters	High – requires proactive management
Run-off entering from outside site boundary	High – requires proactive management
Springs	Dependent on site hydrology/hydrogeology
Run-off and seepage from waste dumps	High – requires proactive management
Run-off & seepage from product stockpiles	High – requires proactive management
Run-off - storm events	High – requires proactive management

The principal source of many water-related issues is incipient rainfall. It is virtually impossible to realistically reduce the volume of rainfall impinging on a site. The creation of void space during quarrying activity also means that once present on-site, rainwater must be actively managed in order to either use beneficially or discharge it from the site as efficiently as possible. A mix of preventative, control and treatment strategies is likely to be the most effective approach at the majority of abandoned sites undergoing regeneration. For example, a 40-meter filter strip of undisturbed native vegetation adjacent to all watercourses is one of the best available means of protecting water quality (DPIWE, 1999).

- Consideration should be given to the point of discharge of any dewatered or surplus process water and means of discharge to prevent pollution to rivers, ditches or pools.
- Use water recirculation system (settlement pond to remove suspended solids and recover water for processing reuse) where possible to minimise water use and wastage.

In the event that preventative and control measures do not completely prevent the transfer of contaminants into on-site or off-site water, some treatment may be required in order to comply with the site discharge consent. Examples of treatment options for potential contaminants are summarised in Table 4.

Table 4: **Contaminants and potential treatment options**

Potential Contaminant	Treatment Options
Non-dissolved contaminants	
Turbidity - suspended solids (silt & sand)	Desilting lagoons and ponds Wetlands Clarifiers Filter presses Chemical treatment (flocculants)
Lubricants, waste oils and petroleum products	Oil/water separators
Sewage and pathogens	Chemical treatment (activated charcoal, chlorination, ozonation)
Dissolved contaminants	
Heavy metals	Precipitation (using lime, caustic soda and other chemicals), followed by solid-liquid separation Wetland (natural ecosystems capable of removing dissolved metals)
Sulphate	Precipitation (with barium chloride)
Chloride - salinity	Desalination Reverse osmosis
Alkalis	Neutralisation with acid
Flocculents	Chemical treatment (appropriate to specific flocculent)
Eutrophicants (e.g. nitrates, phosphates)	Chemical treatment (precipitation) Ion exchange Reverse osmosis
Acids (e.g. sulphuric acid)	Neutralisation with alkalis
Ammonia-based reagents	Ion exchange
Process chemicals	Chemical treatment (appropriate to specific process chemical)
Soaps/detergents	Chemical treatment (destruction)

Groundwater may need a specific set of treatment techniques (see Table 5).

Table 5: Summary of groundwater remediation techniques (Environment Australia)

Technique	Contaminant applicable	Advantages	Disadvantages
Groundwater pump and treat	All	Reliable design can contain and treat groundwater Offsite treatment systems options (e.g. precipitation, biodegradation, chemical treatment) including waste discharge to other liquid waste treatment facilities.	Disposal of treated groundwater Time Pumping can migrate contaminants and smear separate phase hydrocarbons
Air sparging	Organics (particularly volatiles)	Onsite Relatively low cost	Treatment effectiveness can vary with on site conditions Time (duration)
Separate Phase Recovery	Light organic liquids (e.g. fuels)	Reduce source of groundwater contamination Potential to reuse the recovered organic liquid.	Time Disposal of liquid if not able to reuse or recycle
Pump and offsite disposal	Inorganics and organics	Low cost Uses existing treatment facilities	Impact on offsite wastewater facilities. Pumping can result in migration of contaminants or smearing of separate phase hydrocarbons Time
Containment (including cut-off barrier, groundwater diversion, hydraulic containment)	All	Low cost Applicable where many other techniques not practical Time	Ongoing monitoring Liability retained Disposal of water if hydraulic containment employed Ongoing maintenance
Natural attenuation	Organics	Low cost Takes advantage of natural processes Minimal intervention	Ongoing monitoring requirement

Capital costs for treatment systems are typically linked to the volume of water requiring treatment, rather than the degree of treatment required. It is therefore important to consider means of volume reduction where total prevention is not possible. With the exception of low-tech desilting operations and the separation of oil and water using simple physical separators, most treatment options are expensive capital and operating costs, and may require an extended period for construction and commissioning (i.e. they may not be immediately available for treatment duties). The potential cost of treatment emphasises the importance of preventative and control measures, not just from an environmental perspective, but also from a cost-control perspective. Treatment options must also be judged against other criteria:

- Risk of failure.
- Environmental performance.
- Environmental liability.
- Degree of proven operational capacity.
- Operational cost.
- Capital cost.
- Response time.
- Operational reliability.
- Reliance on limited supplier(s).
- Theoretical understanding of process(es).
- Capacity to integrate with existing process(es).
- Degree of engineering flexibility to respond to future changes in regulation.
- Degree of operational flexibility to respond to future changes in regulation.

Water Quality Monitoring

Wardrop *et al* (2001) note that the key to effective prediction of impacts on the water environment is an understanding of the interaction between the site geology and hydrology. This can only be achieved by site investigation and associated analysis and research, and these should be tailored and targeted according to the nature and complexity of the site. Ideally, the implementation of a water monitoring programme should be preceded by the collection of baseline information describing site-specific conditions as they exist prior to the begin of quarrying activity. This is not always possible and is more applicable to future operations rather than those that have already begun the production process. Baseline measurements should be agreed with the relevant regulatory authority and other stakeholders (as appropriate) and should include information relating to:

- Site geology and mineralogy.
- Overburden characteristics.
- Hydrology.
- Groundwater.
- Surface water (including pre-quarrying quality).
- Ecosystem health and diversity.
- Geomorphological information.

Prediction of potential water contamination or pollution issues is essential if effective preventative, control and remedial treatment strategies are to be implemented. In principle it is never too late to use predictive methods to identify future issues. However, the optimum time is prior to the outset of a particular operation or activity, particularly those that have been identified previously as a potential source of problems. This does not imply that control and treatment will not be required, but it does increase the options for planning economically, technically and environmentally sound approaches to problems identified, and may reduce the need for costly ongoing remedial treatment. Effective prediction also ensures the costs of preventative, control or treatment measures are fully accounted before commencement.

One of the first and most cost effective measures that can be taken in preventing the contamination of water resources is the use of a water monitoring programme as an ‘early warning system’ to identify developing problems. The following environmental monitoring schedule is for guidance only, and relates specifically to water management and protection. It should be adjusted to the characteristics of individual quarry sites and extended to include other elements (e.g. land and air quality, ecological aspects, noise and community issues) as appropriate. It is necessary to draw up recording sheets for each environmental parameter monitored. Dependent upon the site location, access to equipment, technical expertise and availability of finance, these recording sheets can record data by hand written entry or by computer entry. Commonly monitored parameters used to determine water quality include:

- pH.
- Dissolved metals.
- Total dissolved solids.
- Total suspended solids.

- Acidity.
- Alkalinity.
- Dissolved oxygen.
- Chemical oxygen demand.
- Biological oxygen demand.
- Nitrate.
- Salinity/chlorides.
- Sulphates.
- Process chemicals (to be specified according to past site operations).

Whichever monitoring protocols are implemented, it is essential that they are adapted to site-specific requirements and represent good value for money. Equally important is recognition and acceptance of the monitoring programmes by other stakeholders, in particular regulators and planning authorities. Therefore, ideally the monitoring programme should be developed in collaboration with stakeholders as appropriate to ensure acceptance from the outset.

If the monitoring programme is to be effective, it is imperative that the concepts of what to measure; where and when to measure it; how to measure it and which evaluation methods should be defined before data collection begins. Sample collection, sample analysis and data handling must all be carried out using standard procedures, agreed with the appropriate environmental agency and/or other relevant stakeholders. Given that the quality of the monitoring programme is dependent on the quality of sampling, sample handling and sample analysis, first steps in the environmental monitoring programme should be a review of internal and external capacity to collect and analyse samples, and evaluate the resulting data.

Sources of Best Practice Information

- Mitchell, P. 2004. *Water Resource Protection and Management*, in Environmental Handbook, UK Quarry Products Association (in press).
- Macfarlane, M. and Mitchell, P. (2003) *Scoping and Assessment of the Environmental and Social Impacts of River Mining in Jamaica*, Warwick Business School, University of Warwick.

30 Management of Air Quality (relevant to coal and iron ore)

To avoid the generation of dust from site activity during and after regeneration and to minimise the consequences of dust affecting nearby communities and land uses:

- Designate buffer zones or margins in which certain activities liable to generate dust are prohibited.
- Signpost roads to give speed limit indications.
- Ensure roads are adequately drained and maintained.
- Consider controlling dust when necessary in dry conditions using a water bowser or other damping agent.
- Use tree planting or vegetation to reduce wind blow and to help filter out airborne dust.

Source of Best Practice Information

- Environment Australia (2000) ‘Best Practice in Rehabilitation and Revegetation’.

31 Clean-up of Soils

A considerable body of knowledge has been developed on how to assess the significance of contamination, but its main focus is urban land development. However, much of it can be applied to contaminated land as it applies to abandoned coal and iron ore mines.

Contaminated soils should be assessed on a case-by-case basis, and left in place or excavated and disposed of in approved manner as appropriate to the regeneration plan. Clean up may involve excavation and removal of wastes/contaminated soil (mechanical, physical and hydraulic means), relocation of wastes (away from streams, to engineered repositories/disposal sites, on-site or off-site) or on-site or off-site treatment. Overall, the approach taken should reflect the need to protect all biophysical aspects of soils, to render a site acceptable and safe for the long-term continuing use and to maximise the options for future use of the site, not proceed if the process is likely to cause more harm than leaving the site undisturbed and consider the public and occupational health impacts associated with remediation and assessment works.

Source of Best Practice Information

- Environment Australia (1999) Contaminated Sites, *Best Practice Environmental Management in Mining*, ISBN 0 642 456460.

32 The Clean-Up Process (relevant to coal and iron ore)

The following sections outlines the main steps necessary to achieve the successful clean up of contaminated land. A typical sequence of events is comprised of seven principal stages. Some of these stages may overlap, be run in parallel or in a linear sequence as determined by the nature of the site, the available information and actions required:

Stage (i)	Identification of potentially contaminated land.
Stage (ii)	Selection of high concentration indicator contaminants (e.g. those that are likely to be present at the greatest concentrations based on the results of Stage (i)).
Stage (iii)	Determination of exposure pathways and risk assessment.
Stage (iv)	Evaluation of the most appropriate remediation technology.
Stage (v)	Confirmation of choice through laboratory and field trials.
Stage (vi)	Implementation and evaluation.
Stage (vii)	Verification of remediation.

Defining the problem, identifying solutions and putting remedial strategies into effect must all be properly planned, supervised and supported (where necessary with specialist expertise to supplement in-house skills). It is essential that the most appropriate type of remedial action is selected, that the action is implemented according to pre-defined standards and that the standard of remediation achieved is verified and properly documented. There are a number of factors that need to be considered in developing an effective and efficient remediation solution. These include risk management, technical practicability, feasibility, cost/benefit ratio and wider environmental, social and economic impacts of a specific approach. Key factors in decision-making include:

- Driving forces for the remediation project.
- Risk management.
- Sustainable development.
- Stakeholders' views and perspectives.
- Cost effectiveness.
- Technical feasibility (Bardos, 1993).

Stage (i). Identification of potentially contaminated land

The identification of potentially contaminated land should begin with a review of the site history and assessment of any available sampling and analytical data. As an additional preliminary step, understanding or defining causes of contamination can assist in identifying areas where there is a high potential for contamination. Potential causes might include:

- Leaks or spills from tanks and pipes.
- Accidents and spills during storage or transport of raw materials, intermediate products and waste materials.
- Disposal of waste materials on or adjacent to the site.
- Stack emissions resulting in contamination of the surrounding environment, particularly downwind.
- Demolition of building (past and present) that contained contaminated material (e.g. asbestos, impregnated brickwork).
- Movement of contaminated groundwater onto the site.
- Migration of toxic gases from adjacent land or underlying strata.
- Leaks from drains from process areas.

Typically, assessment of a potentially contaminated site is undertaken in two phases:

- *Phase 1 – Desk study with a probable site visit*
  Information on current and historical uses of the land is sought and acquired. Potential contaminants are identified. Form of contaminants, effects on air, soil and water, effects on building materials, extent and nature of contamination on-and off-site, geotechnical parameters such as foundation design, slope, stability, underground structures or obstructions, and safety precautions for site personnel are assessed. The desk study should also identify likely hazardous materials, sensitivity of targets around the site to contamination and the likely pathways by which contaminants may move. Information sources may include maps, town plans, public records, aerial photographs, fire insurance plans, trade directories, mineral records, mine plans, journals, registers and archive reports, archaeological reports, bomb incident reports, previous site owners, regulatory authorities, landfill operators, utility suppliers, waste disposal authorities, local people, workers and historical reports (BSI, 2000).

- *Phase 2 – Additional sampling and site investigation*
  Following a thorough desk study, trial pits, boreholing, probing methods may be used to provide details of ground-type and generate samples for analysis. *In-situ* analysis and monitoring may be also undertaken. Analytical data are compared with target levels. Ideally, site investigations should be staged in order to minimise cost, and because some issues will only become apparent following the initial investigations. Neither is it necessarily the case that the complete characterisation of a site is possible in a single site investigation. Sampling techniques can include:

  - Targeted or judgemental sampling, designed to identify if contamination exists when the likely sources of contamination are known.
  - Systematic sampling on a grid or random basis across the site (useful where sources of contamination may be unknown).
  - Stratified sampling which may incorporate a mixture of judgemental and systematic sampling or systematic sampling at different sampling densities across the site.

  Data collected during site investigations are used to establish two things: the risk presented by any contamination and the standards of remediation required in order to reduce the risks to acceptable levels. Data are used in tandem with previous experience of the project designer or in some cases the end-user, along with published information (e.g. theoretical and practical technical reviews, case studies, vendor information, and independent assessments by regulatory authorities or other relevant bodies). These are then supplemented by additional site investigations as necessary and treatability studies to assess and confirm the application of one or more potential treatment technologies.

Treatability studies can be undertaken at laboratory, pilot or full-scale as appropriate). Generally, laboratory-scale studies are used to screen unsuitable technologies and derive initial indications of operating parameters etc, while larger-scale studies are used to assess those factors that cannot be accounted for in the laboratory, including the practical consideration of scale-up (i.e. can what works in the laboratory be successfully transferred and applied at full-scale).

It is extremely important to recognise that any assessment of potentially contaminated sites is only as good as the available information or data generated during any subsequent site investigation. For example, if the site investigation fails to identify ‘hotspots’ containing elevated levels of contamination or the full range of contaminants or soil characteristics, then the chosen remedial approach may not be adequate or even appropriate (see Ramsey (2002) for examples of how ‘hotspots’ can easily be missed through use of the wrong sampling approach). Equally, if samples used in small-scale studies as part of the process of identifying suitable remedial approaches are not representative of the actual field conditions, there may be performance issues when attempting larger-scale field trials and implementation.

Stage (ii). Determination of exposure pathways and risk assessment

A risk-based approach should be adopted. The assessment of land contamination risks involves three main components:

- The source of contamination (e.g. metal contaminated soils, a leaking oil drum) – from analysis of soil samples and comparison against trigger levels an initial judgement on the degree of contamination of a soil can be made.
- The pathway (the route by which a target could come into contact with the contaminating substances). The risk to humans, and the ecosystem in general, posed by contaminated soil depends on there being a pathway by which exposure can occur. Possible pathways include surface water, groundwater and air (toxic fumes, dust etc).
- The target (i.e. the entity that could be adversely affected by the contamination e.g. humans, groundwater, ecosystems etc). The types of target will be influenced by the end-use proposed for the land (e.g. agricultural, recreational or commercial/industrial). Consideration must also be given to the fact that targets may also include individuals that are generally susceptible (e.g. children) or susceptible to specific contaminants.

In broad terms, pathways can be subdivided into categories, with each category assigned principal targets, as shown in the table below.

Table 6: Pathway categories and principal targets

Category	Target	Example
Soil ingestion	Children Livestock Adults Other fauna	Pica (deliberate soil eating) Soil consumption during grazing Consumption of unwashed root vegetables Consumption of roots
Pasture herbage	Livestock	Grazing cattle, sheep
Foodstuffs	Vegetables Cereal crops Meat and fish products	Surface contamination, uptake in tissue Uptake by shoots Bio-concentration in edible body parts
Water	Human consumption Livestock consumption Vegetative uptake Other fauna/flora	Potable water Potable water Uptake from pore water Ingestion

Dust ingestion	Human Livestock	Direct/indirect ingestion of airborne particulates
Dust inhalation	Adults Children Livestock Other fauna	Inhalation of airborne particulates
Dermal absorption	Humans Other fauna	Contact with contaminated soil

The significance of each pathway is dependent on the contaminant, the presence or proximity of targets, and other site-specific factors that may mitigate or aggravate any potential impact. Of great significance is the sensitivity or susceptibility of particular targets and – in the case of living targets – any detoxification mechanisms that they might exhibit (e.g. ability to excrete or detoxify certain metals with no health impacts). Examples of pathways are shown in Table 5. It is important to note that multiple targets can be affected by a single source, and that humans are often not the ultimate targets. This list is by no means exhaustive and a large number of permutations, combinations and cycles are possible, the likelihood of which must be reviewed by use of appropriate risk assessment methodologies.

Table 7 Examples of target/pathway interactions

Source	***Pathway***	**Target**	***Pathway***	**Target**	***Pathway***	**Target**
Direction of contaminant 'movement'						
Soil	*Porewater*	Vegetation	*Consumption*	Herbivores	*Milk/meat*	Humans
Water	*Ingestion*	Herbivores	*Milk/meat*	Humans		
Soil	*Porewater*	Vegetation	*Consumption*	Humans		
Water	*Consumption*	Humans				
Air	*Inhalation*	Humans				
Soil	*Ingestion*	Humans				

In order to determine whether (and how) to treat contaminated land a risk assessment involving the characterisation of the relationship between these three components must be undertaken. This may typically include delineation of the source, measurement and modelling of fate and transport processes along the pathway, and assessment of the potential effect on, and behaviour of, the target. Consideration of risk must not only take account of the existing situation but also the likelihood of any changes in the relationship between the components in the future (e.g. as a consequence of a change in the end-use of the site). If the risk for a 'no-action' alternative is acceptable, then no remediation is necessary. If the risk is not acceptable, then an appropriate remedial technique must be chosen (see Stage (iv) and Stage (v)).

Stage (iii) Establishing treatment targets

The highest concentration contaminants may not always be the most significant – this will be determined by the risk associated with the specific contaminant, for example through consideration of the pathways between the source and targets – see Stage (iii), and the relative 'trigger' concentration at which action is required. Guidance on different targets (i.e. health, environmental and ecosystem based) can be found in a number of publications including:

- Human health risks – National Environmental Health Forum, 1996, 'Health-Based Soil Investigation Levels'.
- Environmental risks – ANZECC Guidelines, 1992; Environmental Quality Objectives in the Netherlands Ministry of Housing, Spatial Planning and the Environment, 1994.

- Ecosystem impacts – Environment Australia, 'National Framework for Ecological Risk Assessment of Contaminated Sites'.

Stage (iv). Evaluation of most appropriate remediation technology

Evaluation provides an objective basis for the selection and design of remedial strategies (of which remediation technologies are likely to be a significant part) and also for operational control during the implementation phase (see Table 8).

Table 8. The main elements of evaluation systems (Harris, 1993).

Stage of remediation	Factors to be evaluated	Protocols to be followed
Selection and design	• Applicability of remedial options • Effectiveness of remedial options • Feasibility and cost of remedial options	• Selection, evaluation and screening procedures using specified selection criteria
Implementation	• Progress of the works against technical specification • Progress of works against budget and schedules	• Technical monitoring procedures • Project monitoring procedures against pre-defined budget and schedule
Post-treatment verification	• Standard of remediation achieved • Tolerance achieved	• Validation and/or long-term monitoring procedures

When considering the choice of the most appropriate remediation technology, there are a number of general and more specific factors and questions to consider (Smith, 1993):

- What is the value of the redevelopment opportunity?
- What is the availability and cost of resources (e.g. materials, specialist contractors)?
- Is sufficient space available on-site to conduct remediation using the chosen approach?
- Will the technology deliver an appropriate level of clean-up in the time available?
- What are the planning and regulatory requirements?
- Does the site host existing services and if they are to remain in place will the chosen technology impact them?
- Are listed buildings or other man-made artefacts present?
- What will the impact of remediation be on present and intended topography?
- Constraints arising from adjacent land areas (e.g. proximity of buildings and current or future uses of adjoining land) – will the chosen technology prevent the movement of contaminants onto or below bordering areas?
- Are surface drainage patterns and proximity of watercourse relevant to technology?
- Are underlying aquifers present and will groundwater levels and movement be positively or negatively impacted by the remediation technology?
- Is there a tendency for the site to flood?
- Is the site of interest with respect to biodiversity, ecosystems or specific species?
- Are health and safety considerations (workers and neighbours) adequately addressed by the technology based on the contaminants requiring treatment?
- Are future changes of land use (i.e. post-remediation) possible or likely and will the degree of proposed clean up suffice for the likely alternative future end-uses?

- What are the requirements for post-remediation monitoring or maintenance and what are the related cost implications?
- What are the stakeholder interests or perceptions of the remediation technology?

More specific factors can be broadly divided into six groups:

- Suitability based on contaminant type (e.g. contaminant(s) determined as important in Stage (iii)).
- Suitability based on soil or waste type(s) requiring treatment.
- Process-based constraints.
- Technology-based constraints.
- Proposed end-use for the site.
- Environmental, social and economic impacts of the technology.

Each of these is addressed in detail below. Although a technology may appear suitable, concerns may still exist for a number of reasons (Bardos, 2001):

- Previous performance of technology in dealing with risk management problem.
- Ability to offer validated performance information from previous projects.
- Expertise of the purveyor.
- Acceptability of the solution to stakeholders who may have expressed preferences for a particular solution or have different perceptions and expertise.

Generally, concerns relating to feasibility tend to be greater for innovative remedial approaches, even if these have been applied over an extended period in other countries (see Stage (iii)). However, it is often these innovative solutions that are seen to offer more in terms of reducing environmental impacts and promoting sustainable development. From a risk management perspective, process-based remediation technologies are applied to control or remove the source of contamination. They can be sub-divided into five types of process:

- Physical processes are used to remove contaminants from the soil matrix, concentrating them into reduced volumes that can then undergo further treatment and/or disposal. Physical processes include particle separation, solution washing, evaporation, screening and classification, separation based on magnetic fields, and soil washing.
- Chemical processes in soil treatment systems have the potential to destroy, fix or neutralise contaminants. Chemical processes include, but are not limited to oxidation, reduction, solvent extraction, neutralisation, precipitation, and polymerisation.
- Biological processes involve the transformation or mineralisation of contaminants to a form that is less toxic, more mobile or both. Biological processes can also be used to fix and accumulate contaminants in recoverable biomass (e.g. plants that accumulate metals). Biological processes generally involve a combination of moisture addition, nutrient addition, microbially available oxygen, microbial inocula, surfactants to increase contaminant mobility, increased soil temperature, normalisation of soil pH.
- Solidification processes are those that encapsulate waste in a monolithic solid with high structural integrity and low relative surface area. Contaminants are not specifically targeted; rather the complete mass of contaminated material is included. Solidification is often associated with stabilisation, which is used to reduce the mobility (i.e. leachability) of the contained contaminants. This is particularly important where the conditions within the solidified mass would otherwise be likely to lead to the leaching of contaminants (e.g. the leaching of certain metals such as zinc and aluminium from alkaline cementitious solidified masses). The process includes sorption of contaminants within the solidification matrix, chemical stabilisation of the contaminants, and in the case of vitrification, associated thermal treatment of organic contaminants.
- Thermal processes are those based on incineration, gasification or pyrolysis at elevated temperatures. They can be single or two stage processes – in the former the destruction

of the target contaminants occurs within the soil matrix, while in the latter the target contaminants are removed from the soil by volatilisation and pyrolysis with subsequent removal or destruction by combustion or condensation. Contaminants treatable by thermal processes include organic compounds, thermolabile inorganic compounds and volatile metals such as mercury (the latter are removed but not destroyed). Most organic compounds are destroyed by combustion during thermal processing. Thermal processes produce solid residues such as ash and treated soil and gaseous process emissions that generally require further treatment.

Theoretically, within these five process types there are a large number of remediation technologies available to address contaminated land issues. However, the actual choice is constrained by a number of factors such as applicability, technical limitations and cost. Process-based remediation technologies may be applied *in-situ* (where ground disturbance is minimised), *ex-situ* (where excavation of the soil is required) or both. *In-situ* treatments can be broadly divided into those in which the treatment agent (solvent, chemical, microbe, solidification agent) is applied at or near the surface or at greater depth, and those in which the process is applied directly (e.g. vitrification, vapour phase extraction) without use of a treatment agent. *In-situ* treatments may be limited by difficulties in ensuring complete contact between the treatment agent and contaminants, making the contaminants available to the treatment agent and ensuring that the treatment has been applied effectively.

Ex-situ processes can be divided into those that are undertaken in vessels and those undertaken in beds, banks or windrows. In vessel systems, accessibility is a function of the efficiency of mixing between the contaminants and biological, chemical or solidification treatment agents, process heat in thermal systems, or process extractants in physical systems. Poor mixing in thermal systems can be overcome by increased retention to allow greater conduction. Larger soil particles must be broken down in the case of other treatment approaches, and often the most effective and convenient method of doing this will be by forming slurry from the soil. Banks, beds and windrows are a compromise between leaving the soil *in-situ* and treating it in a vessel. Turning and cultivation can be used to improve accessibility through a degree of mixing, though this is not to the same extent as that possible in a vessel. However, soil treated in beds, banks or windrows does not need to be reconstituted (i.e. the soil structure is less impacted), unlike soils treated as slurry in vessels. Soil remediation techniques are summarised in Table 9.

Table 9: Summary of soil remediation techniques (derived from Environment Australia)

Technique	Contaminant applicable	Advantages	Disadvantages
Bioremediation (landfarming, biopiles, bioventing)	Organics	Low cost Natural process Onsite or offsite depending on the site conditions and contaminants	Ineffective on inorganics Inhibited by metals & low pH Time Uncertain performance in some cases
Containment / Capping	All types	Beneficial where landfill access is limited Reduces recharge to groundwater Reduces exposure to surface contaminants Low cost In many cases it is the only practical alternative (e.g. tailings management)	Long-term liability Long-term management plan and maintenance required Ongoing monitoring Restrictions on activities in capped area Perception
Incineration	Inorganics & organics	High effectiveness	Large energy requirements Air discharges Disposal of ash required Cost Public perception
On-site vitrification	Organics, heavy metals & radionuclides	Treatment of various wastes simultaneously 25—50% volume reduction Applicable to highly hazardous material Effectively encapsulates metals and radionuclides	Large energy requirements Requires removal/puncture of sealed containers to prevent hood overheating High cost Limited Availability
Off-site disposal	Inorganics & organics	Removes contaminants from site Availability and cost in urban areas Time	Landfill access and volume restrictions Restrictions on disposed material
On-site repository	All types	Highly effective Reduces area requiring management	Long-term liability Long-term management plan required Leachate management required
Soil washing	Inorganics & organics	Reduce volume to be treated	Only suitable for soils with a low percentage of fines Cost Residual material (fines or sludge) may still require treatment or disposal

Stabilisation & solidification	Metals	Effective for metals May be cost effective alternative to offsite disposal (with some restrictions)	Other contaminants affect stabilisation process Material can be left onsite Ongoing monitoring may be required
Stabilisation & solidification (offsite)	Metals	Effective for metals Allows landfill disposal of material otherwise unacceptable	Other contaminants affect stabilisation process Cost
Thermal desorption	Organics	No ash produced Minimises soil damage Time	Requires emission controls Low pH may corrode system Cost Ineffective for metals

33 Soil Handling (relevant to coal and iron ore)

Soil is an essential medium for vegetative growth (and the many benefits that that brings with it). The need for soil should be lead by site assessment, regional context and end use requirements. Local knowledge and experience will be particularly helpful when considering when to remove and replace soil without damaging it.

- If topsoil is stockpiled for a long period of time, its quality deteriorates. If topsoil is no longer available or suitable for revegetation then subsoil, overburden or waste rock may have to be considered as alternatives.
- During the regeneration process, avoid sensitive habitats for temporary or permanent topsoil storage.
- Do not store material on slopes – use flat areas.
- Maximize the distance between storage areas and surface waters.
- If deposition is permanent, revegetate as quickly as possible with appropriate local species to stabilize area (EBI, 2003).
- Avoid compaction as this may lead to reduced infiltration and increased runoff (Strock, 1998).
- Avoid unnecessary handling of soils to avoid further loss of quality.

Soil Replacement

- Replace soils along contour to reduce erosion and increase water storage.
- Respread topsoil uniformly over the area at a suitable depth to support revegetation.
- Leave respread soil with a rough surface with many suitable locations for lodging and germination of seeds.
- Rip, plough or manually cultivate smooth surfaces to improve the 'roughness' of the seedbed and provide suitable sites for lodging and germination of seeds.
- Avoid spreading soil when it is saturated or sticky, as compaction and other damage to the soil structure will occur.
- Take extreme care when importing topsoils as they may contain seeds of persistent and robust weeds.
- Deep rip all compacted areas along the contour before or after spreading topsoil to promote water infiltration and root penetration. Ripping should be carried out when the soil is relatively dry to increase soil break-up. Ripping after soil spreading will also to

‘key’ in the soil to the underlying material, and it provides a rough surface for seed application.
- Apply surface mulches around growing seedlings to reduce erosion, reduce weed establishment, conserve soil moisture, as well as adding useful nutrients and organic matter. Note that surface mulches may inhibit seed germination in some species.

Soil Micro-organisms

- Re-inoculation with beneficial soil microorganisms may be necessary where long-term or inappropriate soil storage has resulted in their depletion.
- If the soil is infected with plant pathogens then that should be addressed via segregation of the infected soil or treatment with appropriate fungicides as required.

Alternatives to Topsoil

Where topsoil is not available on site, alternatives must be sought - these may include any clay material available on site, any overburden that includes a high proportion of fines, highly weathered rock, or imported topsoils. The chemical and physical characteristics of these alternative materials may need to be ameliorated or improved by the addition of pH modifiers, organic matter, nutrients, and beneficial microorganisms.

- The National Environmental Engineering Research Institute (NEERI), Nagpur, India, has developed a sustainable eco-friendly technology that reclaims and rejuvenates the “soil spoils” left behind by opencast mining. The strategy, known as the ‘integrated biotechnological approach’ (IBA), involves the use of diverse organic materials, for example, industrial wastes such as pressmud (a by-product of sugar mills), and treated sludge (a by-product of paper mills) to build soil productivity. These organic materials, which nourish the depleted soil, are supplemented by the planting of saplings that contain specialized cultures of fungi and nitrogen-fixing bacteria. IBA has been shown to increase the survival rate of plant species found on land impacted by opencast mining to more than 80%. At the same time, it has boosted species’ growth rate by a factor of five (UNDP 1998).

Sources of Best Practice Information

- Environment Australia
- Energy and Biodiversity Initiative (2003) *Good Practice in the Prevention and Mitigation of Primary and Secondary Biodiversity Impacts*, Conservation International, Washington DC.
- *ICRCL Guidelines* (these offer details of the criteria by which the extent of contamination may be judged).
- *BS* 5930 (1999) *Code of Practice for Site Investigations* (British Standards Institution, 1999) – practical guidance;
- *BS* 10175 (2000*) Investigation of Potentially Contaminated Sites – Code of Practice* (British Standards Institution, 2000) – practical guidance;
- *Industry Profiles* – reports written by the Department of the Environment and ICRCL.
- *Contaminated Land Report 3:* Documentary Research on Industrial Sites – written by the Department of the Environment, sets out the process of historical research for old industrial sites to enable the development of a site to be traced from its beginnings to the present.

34 Revegetation and Afforestation (relevant to coal and iron ore)

As noted above, the establishment of a self-sustaining cover of vegetation is the best low maintenance long-term method of stabilising disturbed sites. Generally, the vegetation type that existed before the disturbance or a similar vegetation type will be most successful afterwards, following an initial reestablishment period (assuming that the soil type, topography, drainage patterns etc that existed before have also been recreated in part or wholly).

Revegetation may aim to establish native plants, pasture, a plantation for forestry purposes, or other approved means of land stabilisation. It should be remembered that establishment of non-native vegetation types often requires more input than reestablishment of the original vegetation. Soils for exotic species must be relatively fertile and maintenance treatments such as fertilising and thinning may be necessary. The use of single species versus multiple species depends on a number of factors including soil tolerance, species availability and aesthetic aspects and the wishes and needs of local communities (Noronha 2000). However, the use of a range of different tree species reduces the risk of loss of cover because of their different abilities to withstand environmental extremes.

Noronha (2000) observed that for the iron ore mines in Goa, the favoured reclamation practice of land impacted tailings or overburden disposal has been afforestation. The trees commonly grown were acacia auriculiformis, cashew (*anacardium occidentale*), casuarina, soobabul (*Leucaena leucocephala*), neem (*Azadirachta indica)* and khair (*Acacia catechu*). However, these trees were planted often with no particular end use in mind. Therefore, although afforestation with a fast growing species (e.g. acacia) may allow a site regeneration plan to comply with environmental regulations, alternative reclamation options and the technologies required to implement these must also be properly assessed to maximise the environmental, social and economic benefits of reforestation.

It is essential that the stressors that are likely to inhibit the reintroduction of plant cover are identified *prior* to beginning revegetation efforts.

Sources of Best Practice Information

- Pennsylvania Department of Environmental Protection. 1998. *Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania*.
- Department of Primary Industries, Water and Environment (DPIWE). 1999. Quarry Code of Practice, Environment Protection, Planning and Analytical Services Division, Hobart, Tasmania, ISBN: 0 124 662294.

35 Species Selection (relevant to coal and iron ore)

- The selection of species for revegetation generally depends on the future land use, soil conditions and climate of the area.
- Non-weed plants, which are colonizing disturbed sites adjacent to native vegetation, are likely to be useful for rehabilitation.
- Non-local native species may be required in some areas where the site has been impacted to such an extent that the original natives cannot establish under the altered conditions even after regeneration. Hardy short-lived colonizer species should be sown, in order to allow the naturally occurring species to move in and dominate over time.
- Exotic grasses and clovers can quickly provide vegetation cover and a fibrous root mat that can bind the soil against erosion. On steep or highly erodible sites, it may be necessary to provide a fast growing cover crop to stabilise the soil while the native species become established.

36 Fertilising (relevant to coal and iron ore)

- Fertiliser application is a relatively inexpensive treatment, which will promote growth of both exotic and native species. Care should be taken when fertilising native vegetation because excessive application rates can encourage weed invasion, and even chemically 'burn' native species.
- Where necessary (especially if the topsoil has been lost) repeat fertiliser applications every 1-2 years until vegetation is healthy and self-sustaining.
- While chemical fertilisers are cheap and easier to apply, they are generally highly soluble and some of the nutrients will be carried away in run-off if there is no topsoil, or plant root systems to bind up the nutrients.
- Long-term management may be essential in some cases to successfully revegetate materials with limited positive chemical or physical characteristics. For example, waste dumps at Noamundi Iron Ore Mines are loose, sandy, erodible materials consisting of boulders, devoid of organic matter and moisture retention capacity. Addition of fertiliser in combination with organic manure resulted in more than double the growth of the unfertilised area (Dhar, 2000).

37 Planting and Seeding (relevant to coal and iron ore)

- In most cases, revegetation will involve the re-introduction of suitable plant species to supplement regeneration via wind borne or soil stored seed. This reintroduction can be as nursery propagated seedlings, or through the direct application of seed to the prepared seedbed or a combination of both as appropriate.
- Planting nursery-grown seedlings is relatively expensive and labour intensive, and planting shock and animal browsing may slow tree growth.
- However, where successful, it can provide the most rapid greening of a site. This method is most suitable for small but critical areas.
- Seeds to be used in regeneration should be collected in and around the area of the abandoned site
- Seed should be stored in airtight containers in a cool, dry and dark location. Longevity of seeds depends on the species concerned. Addition of insecticides and fungicides to stored seed may increase longevity. Native seeds may be treated with smoke or smoked water to increase germination rates.
- There are a number of seeding methods:
  - *Spreading of seed bearing brush*
  - *Direct seeding methods* - applying the seed and waiting for natural processes to do the rest. Direct seeding methods include: natural seed fall, hand broadcasting of seed and fertiliser (for small areas), hydro-seeding (for large areas or sites where access on foot is difficult), hydro-mulching (for steep slopes) and aerial broadcasting of seed from low flying aircraft or helicopters (suitable for very large sites).

38 Timing of Revegetation (relevant to coal and iron ore)

- Seeding and fertiliser application are usually best undertaken together as close as possible to the onset of reliable rains.
- Seed will generally germinate best if applied to recently disturbed ground. Where the soil has settled and formed a crust that inhibits seed establishment (e.g. on clay soils), some form of cultivation or harrowing of the ground surface prior to seed application is likely to improve seedling establishment.
- Planting of seedlings should be carried out in early spring. It is important that seedlings become well established before drier weather.

39 Weed Control (relevant to coal and iron ore)

- Care should be taken when importing topsoils because they often contain seeds of weeds.
- Weed control (especially of grasses) is always important in the first year where native trees are to be established. Where trees are to be planted or sown into a grass infested area, cultivation, burning, scalping, herbicide application, or a combination of these treatments may be necessary to ensure that the trees become established successfully.
- The use of chemicals can be minimised by spraying at appropriate times of the year/day and when the weeds are young.
- Dense weed infestation may be smothered by flattening with machines and covering the area with a generous layer of soil or overburden that is known to be weed free.

40 Rehabilitation Monitoring and Maintenance (relevant to coal and iron ore)

- Rehabilitation is a process that can take several or many years to produce a stable and self-sustaining ecosystem. Aftercare is important and any failures should be rectified quickly to avoid problems propagating spatially over time.
- Assess the health of vegetation and check for erosion regularly. Pay particular attention to animal browsing damage and weed infestation.
- In areas where germination has failed, enrichment planting (planting seedlings into bare areas) or spot sowing (hand sowing of seed into small cultivated patches) should be undertaken.
- Identify early signs of nutrient deficiencies (e.g. chlorosis – yellow leaves) and rectify with additional fertiliser applications if indicated by soil analysis.
- Natural disturbances such as fire, flood, pests, disease, and drought may potentially impact the success of revegetation. Where revegetated areas are affected by natural disturbances it may be necessary to carry out enrichment planting and/or spot sowing in order to enable the area to recover.
- Repair any significant erosion as quickly as possible.

41 Criteria for Determining Completion of Revegetation (relevant to coal and iron ore)

A third party that is both credible and capable of assessing a company's performance should be agreed upon by all parties in order for performance assessment to be useful (Sweeting and Clark, 2000). Suggested minimum standards for completion criteria include:

- The rehabilitated area is in a stable and non-polluting state.
- The area is suitable for the planned final use or objective.
- Revegetated areas are not affected by continuing erosion.
- The revegetated area is free of weeds.
- Biological criteria (including species diversity, canopy cover and seed production).
- Water quality standards for drainage water are consistently achieved.
- Productivity of food crops is at an acceptable level.

In general terms, a transparent and robust regulatory framework that defines minimum acceptable standards should support the chosen criteria. For example, standards in Minnesota (USA) include:

- Vegetation:
  - ➟ 90% vegetative cover after 3 years (5 years in west and south slopes).
  - ➟ Self-sustaining vegetation after 10 years.

- Surface soil stockpiles:
  - ➟ Side slopes no steeper than 2.5 horizontal to 1 vertical.
  - ➟ Maximum lift height 40 feet.
  - ➟ Minimum bench width 30 feet.

- Rock stockpiles:
  - ➟ Maximum lift height 30 feet.
  - ➟ Minimum bench width 30 feet.
  - ➟ 2 feet of soil cover on top and benches.

- Process waste storage basins (tailings impoundments):
  - ➟ Side slopes generally no steeper than 2.5 horizontal to 1 vertical.
  - ➟ Lift heights generally less than 50 feet.

42 Worker Retrenchment (relevant to coal and iron ore)

Hoskin (2000:42) reminds us that 'with hundreds of thousands of workers displaced through mine closure, consideration needs to be given to issues of income, skills, training, worker mobility (although many workers do not want to move), physical, and mental well-being'. Whether dealing with current or recently closed or abandoned mines, this will include the need for an adequate company severance package to assist workers in their relocation and compensate for future lost income, counselling to help overcome the psychological stresses that accompany unemployment, retraining to help miners successfully gain employment in another industry, and job search facilities to increase the chances of acquiring a new position (World Bank and IFC 2002).

At Pine Point, severance packages played a significant role in the worker adjustment process. The company provided severance payments equal to one weeks wages for each year of service, in addition to $C500 cash bonus. Medical plans and group life insurance were continued for three months beyond the severance date, and a skills inventory of the laid-off workers was also made available to prospective employers. A special Canada Employment centre was established to provide 'customised' assistance to the labour force, providing help with resume writing and job search skills. The federal government and the company also jointly funded travel for job search purposes, and provided up to $C10000 per worker as a relocation package (Kendall 1992). According to questionnaire results the worker readjustment programmes at Pine Point were well received, with 93 out of 125 respondents, finding the programmes 'helpful in coping with the closure and finding a new job.' Kendall[23] found that 75% of miners displaced by closure gave continuing in the mining industry as their first priority. Of all the programmes, the relocation programme was regarded as being the most beneficial, with the Canada employment job search service being cited as the next most beneficial.

The worker adjustment package and accompanying services were negotiated between the company and the government at Pine Point. Alternative models for the provision of these packages and services are possible, and may be generated through co-operation between the company and community, company and the union, or government and the community. However, company co-operation, has become regarded as critical to the successful provision of these services because as well as allowing for their on-site delivery, the company are familiar with individual worker's needs. Company assistance in the establishment of retraining and job search facilities, will largely be attributable to the companies ideology, although the size and geographic location of the company will influence the availability of personnel to assist with the programmes, and the ability of the company to mobilise external support. Whatever model is used, Neil et al (1992) specify a number of components in a comprehensive adjustment scheme, including:

- Financial support to cover job search and relocation.
- Skills inventory for prospective employers.
- Job vacancy listings.
- Development of job search skills.
- Information concerning costs and standards of living in other areas.
- Retraining in specific job skills.

The company and local government policies in place during operations will also have important implications for the adjustment process in the event of mine closure or abandonment. The first concerns for example, the company's policy on the sale of housing. The consequences of home ownership with little market value for displaced miners are a very serious issue. It reduces mobility – an essential prerequisite of new job acquisition. To help deal with this problem companies may be able to employ a buy-back policy, or at least secure a nominal minimum for which the value of the property can be secured.

Strongman (2000) points out that it is necessary to have advance payment of part of the redundancy package so that workers can purchase local land in a phased manner and avoid a large 'land rush' that drives up land prices if severance payments are all released at the same time. Advance notice, if not payment, is accepted as an essential element in successful worker adjustment, providing the lead-time necessary to plan futures, start new local economic initiatives, begin a job search, and negotiate a severance package. At Pine Point, employees were given six months formal notice of the closure, even though legislation at that time in the region requiring none. Companies argue that if the advance notice is too long, however, worker morale will generally decline and the company will lose their best workers early, with detrimental effects on productivity. But, by providing concessions to key workers these problems can be avoided. At the closure of the Selco copper and zinc mine in Ontario in the early eighties, for example, key employees who agreed to stay to the end date were paid 150% of their normal salaries between notification of closure and stoppage (Wolfe 1993).

By retraining mineworkers it is possible to expand the range of employment opportunities available to them in other sectors, and so enhance the possibility of them gaining fruitful employment either regionally or locally and sustaining the economy established by mining. There are a number of examples of mining companies providing training in such transferable skills. The US Borax Sustainable Development Programme considers transferable occupational skills as one of its key performance indicators (US Borax 2003). Job-skilling by the company can provide additional support to other economic initiatives of the community after the mine has been decommissioned, as well as increasing the individuals' prospects for employment in other areas (Salisbury 2000).

However, in addition to practical and financial assistance in the readjustment process, it is essential that displaced workers and their families receive some psychological support, to cope with the stresses of unemployment, and the types of negative reactions, that can result. In the Nordic countries, such provisions are effectively made by the public sector. Kieselbach (1987) suggests that where the public administrative support is not in place for such services, these might be provided through the trade unions, with the advantage that individual problems could be perceived in their social context. Alternatively, where there is no union or governmental provision, the progressive company may wish to utilise the resources of a non-government organisation specifically trained in this capacity. It is further suggested that outreach services are available to those, numerous within mining, reluctant to approach agencies themselves for assistance (Neil et al 1992).

Case Study

In April 1999, Placer Dome bought 50% of Western Areas Ltd. (formerly a subsidiary of JCI Ltd.). The company assumed the full management of the joint venture and became known as ‘Placer Dome Western Areas Joint Venture, South Deep Mines’. It has established an office called Placer Dome South Africa (PDSA) based in Johannesburg. Between July and October of that year, the company retrenched 2,560 of its employees (42% management staff, 35% supervisory staff and 30% semi-skilled staff). Most of the staff were from rural villages in Lesotho, Swaziland, Mozambique, Botswana and South Africa. The company’s rationale for retrenchment was based on improving safety and economic efficiency through investment in technology and equipment (www.placerdome.com).

The affiliate of the NUM at the mine-site disagreed on the company’s rationale, bringing their case to the then South African Gold Crisis Committee (since abolished), and then to the Labour Court. They eventually lost but the company had to face negative publicity as ‘the second worst employer in South Africa’ (Resource Speaker: Conference on Environmentally Responsible Mining in South Africa, September 25-28 2001). As a result, the company reviewed the traditional retrenchment package mandated by law in South Africa. This requires an amount of severance pay based upon the length of tenure, on-site training and counselling before the retrenchees go home to their respective communities. Compared to this mandate and the company’s Sustainability Policy (a commitment to integrate social, economic and environmental responsibility into all aspects of its operations) the company package was lacking. Hence, the company committed to a pioneering approach to retrenchment intervention in South Africa and a new and more extensive retrenchment package that additionally included re-skilling:

- As near as possible to the effected employees’ home province rather than mine-site.
- Over a period of two years, not three months as before.
- For the retrenchee’s proxy (a substitute breadwinner) should the retrenchee choose not to undergo re-skilling personally.

Before the retrenchees departed from the mine site, they were given individual counselling in accordance with the traditional retrenchment package. In this process, retrenched employees were informed about the severance package (2 weeks salary for each year of service), separation process, unemployment insurance benefits, provident fund payouts and an exit medical interview. There was also a session on dealing with change and undertaking interviews. Two group guidance sessions followed, reiterating the above information, while a service provider, RUTEC, conducted enterprise counselling with assistance from the Department of Labour.

In 1999 the management of South Deep Mines designed the CARE Project without any external assistance. They decided that it should be aligned with Placer Dome’s Sustainability Policy under the newly created Sustainable Development Department and within their understanding of the framework of the new Social Plan. The present report focuses on the tri-sector partnership and retrenchment component of the CARE project. The goal of the first phase of the CARE project was to enable at least 70% of the retrenched employees or their proxy family members to become economically active within 24 months of retrenchment, thus returning the lost revenue (R300 per month) to the family and community (Malaga 2003).

43 Community Diversification (relevant to coal and iron ore)

Many community members around mines '…converted to miners, merchants or suppliers of mine services over time lose their roots and links with their original communities, forget agricultural skills, and get used to a new way of life' (Fernando 1999). In considering best practice social mitigation and regeneration measures for communities subject to mine closure or abandonment, it is particularly important to develop the capacity of the community to cope again independently. For the economically able in rural developing areas, capacity building should be a key focus of community regeneration efforts so that villagers can re-establish, at a minimum, their ability to grow what they need to cater for subsistence needs (Strongman 2000). However, these effort will need to be complimented by efforts to identify and provide a poverty alleviation safety net for the most vulnerable groups in society (the old, the very young, and single mothers) who may be least able to find ways to cope when family income drops and there is an out-migration of young males.

One of the most significant capacity building efforts involves economic diversification of the community. Through successful economic diversification efforts, it can be possible for the local population to side-step altogether the dramatic social, psychological and economic costs associated with relocation. Furthermore; it avoids the under-utilisation or wastage of public infrastructure; it displaces the need to fund relocation assistance, unemployment benefits, and retraining programmes; as well as the need to fund the establishment of infrastructure elsewhere to accommodate those made directly or indirectly redundant (O'Faircheallaigh 1992).

Haney and Shkaratan (2003) identify a number of diversification mechanisms associated with regeneration efforts around the restructuring of the coal industry in eastern Europe, including the provision of micro-credit to individual entrepreneurs and subsidized credit to small and medium sized enterprises; technical assistance and support for business development through business incubators and workspace centres; and programmes matching job seekers with potential employers through subsidised on the job training or training in other professions, in addition to the more technical local employment offices that provide information on vacancies to job seekers.

In the case of urban communities, support for new business development and micro-enterprise financing can be very important. For example, in Romania in 1998, the government offered a lump sum financial package to encourage workers to leave the coal-mining sector. Over 80000 workers (about half the industry workforce) took the package. However, no measures were undertaken to create new jobs, so the government responded by developing a social mitigation programme to generate new economic activity, including the conversion of disused mine building into workspace centres, technical assistance to help establish small businesses, employment incentives for on-the-job training to create new jobs, and provision of micro-credit facilities (World Bank and IFC 2002), although Haney and Shkaratan (2003) note that the cost-per-job of supporting employment creation at an expanding enterprise is generally lower than at a new enterprise, and that they also have greater potential for absorbing labour.

While diversification has the advantage of decreasing the vulnerability of mining communities, it has often proved difficult given the small size and remoteness of many mining communities subject to closure or abandonment. Nevertheless, there are well-documented examples, where the planning and commitment of residents and government, have made diversification possible. Atikokan, a mining town in northern Ontario, is a small and remote settlement that was subject to the closure of its two iron ore mines. Through complementary small business initiatives such as tourism, light manufacturing, and forestry, and the expansion and upgrading of regional infrastructure, it was able to find alternative economic activities and so sustain the survival of its community. Thus, although closure of the iron ore mines rendered over half the community's labour force unemployed, it subsequently lost less than a fifth of its total population (O'Faircheallaigh 1992).

The widespread closure of coalfields in the UK during the 1980s has provided a number of examples of mining community regeneration initiatives and projects funded through the coalfield regeneration fund, which amounted to £380 million in 2003 (Walter 2003). A number of these projects are managed by Trusts such as the Coalfields Regeneration Trust, which includes representatives of the coal industry, mining communities and regeneration bodies with the purpose of identifying and providing financial backing to projects that help restore prosperous and healthy mining communities. In 1999 they announced projects aimed at helping to tackle poverty and unemployment in former mining villages with the greatest need, including a transport scheme for the disabled, formation of credit unions, and training and health developments (BBC1999).

Many of the interventions to assist former coal mining communities in the UK and in eastern Europe have been successful but have collectively been criticised for providing 'too little too late' (Haney and Shkaratan 2003). More specifically, an interim evaluation of interventions for the Department of Environment, Transport and Regions (DETR) (2002) suggests interventions needed to be better informed by monitoring and evaluation, and better adapted to the limited capacity of coalfield communities and local authorities to meet the partnership and engagement requirements of many interventions since the cohesion of the former had been eroded (a problem compounded by out-migration of young people) and the remit and available budgets of the latter were inadequate to allow for their active inclusion. This review of interventions for the DETR noted a number of key factors for successful mine community regeneration projects:

"*Community consultation* and involvement are critical not only in developing specific and targeted projects but also in encouraging the community to take ownership of the regeneration programme, its purpose and achievements.

Partnership working, at the project level is a vital ingredient in assemblage of a range of interested parties for funding purposes and in providing the necessary mix of specialist skills to implement the various multi-faceted regeneration projects.

Transparent selection procedures through decision-making bodies constituted to provide a balance between funding agencies and objectives and the needs of the area as identified by its residents, businesses and organisations.

Co-ordination and networking not only in ensuring that the project itself is well specified and implemented but also in making the most of linkages with other projects, learning from good practice elsewhere, and encouraging cross-referral between activities.

Community workers based in the community, and, ideally, from the community bring benefits not only in terms of enhancing community interest and buy-in, but in supporting the long-term sustainability of regeneration in the community."

For Strongman (2000) NGOs and their associated community development workers, can act as an important intermediary between the community, company and government, but can most usefully benefit mining or post-mining communities to operate social assets and infrastructure if it fits with their capability and missions and if government does not have the needed capacity. For example, NGOs are helping train mine related local government officials in Papua New Guinea, provide micro enterprise finance in Romania, undertake innovative rehabilitation programmes in Niger and manage mine company community projects in Indonesia. In this regard, mine-related foundations (such as the Rio-Tinto Foundation) may have a useful role to play both in closure planning and regeneration.

The overarching conclusion of Haney and Shkaratan's (2003:18) study of the social and economic impacts of the regeneration of coal mining regions in eastern Europe, was that across all sites it was several years before the various local development efforts and active labour market policies are establishes and begin to have a positive impact, with a 'discrepancy between the swiftness of the emergence of the main problem (large-scale unemployment) and the capacity of the response systems on all levels to react, even under the best circumstances'.

Case study

The Sullivan Mine, in Kimberley, in Northwest Canada, owned by Teck Cominco, has been operating for ninety years before its closure in 2001. During its life, it generated over US$20 billion in revenue and was a major source employment and income for the local government. The potential impact on the local community was therefore extremely significant. The mine helped to establish a Sullivan Public Liaison Committee to ensure that community concerns were heard and that environmental and social issues managed in consultation with the local government, the community, and the NGOs in a transparent way. For the past ten years, the mine has worked in partnership with the local government to attract new investment into the area. The mining company developed a ski hill and provided low cost land for a gold course to be developed by the local government. As a result, they were able to attract a major developer to promote the area as a year-round resort destination. The mining company is also still involved in supporting a residential housing development to attract new residents to Kimberley. Tourism development may not always be easy to replicate in cases of mine closure in the developing world. However, the process by which the mine, the local government and the community has worked together in this case is readily applicable elsewhere (Minerals Council of Australia 2002).

44 Regeneration Monitoring (relevant to coal and iron ore)

In order for stakeholders to evaluate the success and reliability of regeneration best practice measures, criteria must be applied to 'test' the performance of those measures. The assessment criteria as to what constitutes an acceptable level of post-regeneration biophysical and socio-economic quality and sustainability, aesthetic qualities, land use, degree of care and maintenance required and 'one-off' and ongoing costs will vary according to different stakeholder perspectives. Appropriate monitoring indicators is an essential element of the regeneration process, defining performance in terms of original aims and objectives and modifying actions to deal with changes in context or desired outcomes. Monitoring also needs to accommodate those external factors that may change with time. Therefore a long-term commitment to monitoring is required, which will ideally be addressed through the development of local community, business and government capacity (Sassoon 2000).

The primary function of a biophysical monitoring programme is to ensure regeneration targets have been met. The schedule for the programme should be established so it is simple to operate and will provide data that is directly utilised by the relevant stakeholders. The essence of a good programme is to keep it simple, and this is reflected in the programme design:

- Identify the scope of monitoring required and list the sub-programmes corresponding to each environmental issue.
- Define the objectives for each sub-programme.
- Specify how data or information collected will be used in the decision making process.
- Define the spatial and pathway boundaries for the work and select, map or plan scales and sites for direct measurement observation or sampling.
- Based on appropriate characterisation studies, select the key indicators for direct measurement observation or sampling.

- Define how the data will be analysed and interpreted, and how it will be presented in the monitoring report.
- Define the precision and accuracy required in the data.
- Consider compatibility of the data to be collected with historical data and with contemporary related data.
- Set minimum requirements for monitoring air, water, discharges, biological systems.

The following biophysical monitoring schedule is a guide only and should be adjusted for the characteristics of individual sites. It is adapted from a draft of the United Nation's first edition of Environmental Guidelines for Mining Operations. It will be necessary to draw up recording sheets for each biophysical parameter monitored. Dependant upon the site location, access to equipment, technical expertise and availability of finance, these recording sheets will record data by hand written entry or computer entry. In order to properly design an effective and efficient monitoring programme, the principle parameters will normally include aspects of:

1. Land.
2. Climate.
3. Biological systems.
4. Water.
5. Air.
6. Noise.
7. Process effluents and wastes.
8. Community issues.

Equally important are the concepts of *what* to measure; *where* and *when* to measure it; *how* to measure it and *which* evaluation methods should be used subsequent to data collection. Sample collection, sample analysis and data handling must all be carried out using standard procedures. Therefore, where appropriate, one of the first steps in the biophysical monitoring programme will be a review of internal and external capacity to collect and analyse samples and evaluate the analytical data. This may include some of the following elements:

- Assessment of sampling and laboratory manuals, including:
  - ➟ Clarity.
  - ➟ Availability.
  - ➟ Comparison with standard manuals.
  - ➟ Adaptations for site-specific sampling and analytical requirements.

- Assessment of in-house and external training facilities.

- Assessment of sampling and laboratory practice, including:
  - ➟ Choice of sample sites and sampling technique.
  - ➟ Responsibility for sample collection.
  - ➟ Sample collection staff experience, training and qualifications.
  - ➟ Type and size of sample taken.
  - ➟ Sample labelling.
  - ➟ Pre-analysis sample storage.
  - ➟ Assessment of analytical facilities.
  - ➟ Analytical staff experience, training and qualifications.
  - ➟ Use of control, repeat and standard samples.
  - ➟ Responsibility for data interpretation.
  - ➟ Validity of data interpretation (including computer modelling where applicable).
  - ➟ Data interpretation staff experience, training and qualifications.
  - ➟ Data storage.
  - ➟ Response to data interpretation.
  - ➟ Data reporting.

  - Distribution of data and associated reports

- Assessment of factors hindering efficient sample collection and analysis:
  - Sampling equipment downtime
  - Analytical equipment downtime
  - Equipment shortages
  - Absence of power supplies in remote locations
  - Other non-operational sampling sites

Where a shortfall in capacity exists, training, recruitment or the use of external sources of expertise can be used for rectification prior to continuing development of the environmental monitoring programme. What needs to be monitored will be determined by site assessment, the regional context, the end-use (i.e. does the regeneration result in a sustainable end-use) and any other related aims and objectives. It is important therefore to assess the success of actions and indicators put in place. A clear feedback loop should be established between the information collected via performance indicators, and the success of actions put in place to improve performance where targets are not being met. If reporting indicates that performance is not in line with targets, then the regeneration process should be modified as appropriate.

45 Conclusions and Suggestions for Further Research

There is a strongly emerging consensus that regeneration planning specifically, and post-mining closure planning generally, must conceptually and temporally integrate all the aforementioned aspects of good and best practice. Clarke et al (2000) summarises the challenge of integrated mine closure and regeneration as follows:

'Comprehensive mine closure for abandoned mines, presently operating mines, and future mines remains a major challenge for virtually every mining nation in the world. To accommodate the need to close abandoned mines and to ensure that existing and future mines are appropriately closed will require the cooperation of a diverse stakeholder community, new and innovative methods of closure, appropriate financing mechanisms and major policy and legislative change in most nations to ensure post-mining sustainable development'.

The main focus of this paper has been in the identification of best practice regeneration. However, each and every recommendation is, to different extents, specific to its environment, and not necessarily transferable to other contexts where they may be ineffective or inoperable. Many of the practices are also contingent on early warning or prior identification of closure and may not be appropriate when abandonment has already occurred. Nevertheless, many of the aims and objectives of regeneration are the same as if applied to an operating mine (e.g. erosion control, acid generation prevention etc). Therefore, there is a need to further analyse the relationship between best practices for abandoned operations, and those for existing or planned operations so that it can be integrated into the mine management process.

Work with the Global Centre for Post Mining Regeneration could be initiated to develop means by which the success of closure planning and mine site regeneration can be assessed (e.g. development of regeneration-specific indicators to assess and refine regeneration efforts). According to Warhurst et al (1999) 'more research is also required on the socio-economic effects of mine closure and their mitigation, and case study analysis needs to inform the drawing of lessons to design best practice corporate strategy and improved public policy'.

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Mine decommissioning
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APPENDIX 1: Relevant Websites

ANMED
http://www.agso.gov.au/anmed/anmed.html

CAMMA
http://www.mmsd1.mms.nrcan.gc.ca/mmsddev/camma/default.asp

GEMEED-APEC
http://www.gemeed.cl

MIRO
http://min-pc2034.leeds.ac.uk/goodquarry/index.asp

INFOMINE
http://www.infomine.com

Mineral Resources Forum
http://www.natural-resources.org/minerals/index.htm

MPRI-IDRC
http://www.idrc.ca/mpri

ANZMEC
http://www.isr.gov.au/resources/anzmec/index.html

Bolivian Ministry of Mining
http://www.boliviamining.com

Chilean Copper Commission
http://www.cochilco.cl

Geological Survey of Namibia
http://www.gsn.gov.na/

PNG Department of Mineral Resources
http://www.mineral.gov.pg

Phillipine Society of Mining Engineers
http://www.psem.ph

Geological Survey of South Africa
http://www.dme.gov.za

Minnesota Statutes and Minnesota Rules
http://www.revisor.leg.state.mn.us

Minnesota Department of Natural Resources. 1980. Rules relating to mineland reclamation, Chapter 6130
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Annexure-6

Note on Partnership Building Process Based on Our Experience

Managing natural resource wealth in mining areas needs stakeholders to work together or in partnerships, for which a degree of trust in one another is necessary. Trust has broken down in mining areas as a result of various decisions and non-decisions on the part of both the mining companies and the government, which have directly or indirectly impacted the environment and the people living in the area. Trust and partnerships are closely related in that to work in partnerships, trust is needed between the various stakeholders, and one of the ways to build trust is to work together in partnerships. We feel that starting from partnerships, which may be characterized by transparent decision-making processes and accountability of stakeholders to one another, we can build trust between stakeholders so that they are able to work with one another to achieve the goal of sustainable regeneration

From among the study villages, we chose to explore the possibility of building partnerships in those villages, which we perceived to be badly affected. We deliberately left out villages where issues had gotten very politicized, as it would take groundwork and time beyond the scope of the project to build trust and create the necessary environment for stakeholders to partner. We thought that one successful partnership based project would act as a model in the region and would inspire emulation of the process in more complex situations. This approach served our purpose well in that we have recently been approached by community groups and mining industries separately to help mediate and help find solution on such politically charged issues.

We decided to work with one of the eight villages where we had conducted PRA exercises since there was now baseline data for these villages. From these eight, we chose the village of Cudnem because the residents showed an interest in partnering to solve problems. Cudnem is a large village comprising seven smaller hamlets and for reasons explained further on, we realized that working with these hamlets would be equivalent to working in seven villages. Recognizing the time constraint we had to work within, we chose to restrict our efforts to this one village so that we could address the problems in depth.

In Cudnem we are currently working on rebuilding agriculture in the village. The following is a description of the process involved in building the partnership. In this process TERI’s role has been that of a *facilitator*, *catalyst* and a *mobiliser*. While we have worked with all stakeholder groups, we found that from amongst the industry, government and the community, the community was the weakest partner. Therefore we focused our efforts on strengthening the capacity of community members to effectively participate in partnerships. We have attempted to achieve this through numerous discussions with various community groups and dissemination meetings of our research and findings.

Getting stakeholders on board

Government and the Industry

At the start of the project as well as a year into it, we held multi-stakeholder meetings where representatives of the industry, the government and members of the local community were present. Here we explained the ideas that drive our project, as well as the goals of the project. We have also regularly given updates of our progress to representatives of the industry and government through dissemination and consultation workshops. This continuous engagement has ensured that a high level of interest is maintained and that communication channels remain open between industry and government representatives and us, so that there is feedback both ways.

Community

It was more challenging getting the community on board since the "community" does not have a single identity and is not always driven by common motives like the industry or the government may be. Different groups within the community have different and often competing agendas and for partnerships to be successful these need to be considered. Therefore the local community needed to build its capacity in terms of how to address issues among themselves as well as how to participate in partnership processes with other stakeholder groups. This meant we had to go back a few steps.

From the outset it was clear that to participate in partnership building processes the local community needed to be able to represent itself through formal/informal community based organization, associations or other local level institutions as this would help create trust between different community groups as well present a united front within a partnership. But first, an important question had to be addressed: *Who will represent the community?*

Initially we felt that the smallest unit we needed to work with was the village, and that village level representatives would be able to bring to the table, common issues that could be addressed via partnerships. At the village level, the most prominent local level institutions are the *panchayat,* and the *gram sabha.* The former is a council of elected representatives to the government at the lowest level, and the latter is the forum where all the eligible voters of the village gather to deliberate issues of concern to the village. While the *panchayat* is a government agency and therefore does not qualify as the "community" the *gram sabha* was not the preferred choice since it does not function properly due to poor participation.

Consequently, we explored the possibilities of working with citizens' associations at the village level. Since there weren't any village level groups to work with we thought we could help residents form such groups. But we realized that villages can be very heterogeneous compositions of people and can further be broken down into more homogenous units known locally as *wado*s. These are smaller hamlets or wards within a village and often comprise groups of people who may be of the same socio-economic profile and naturally more inclined to work with one another. Therefore, working in the seven wards of the village of Cudnem was the equivalent of working in seven separate villages with different interests. The heterogeneity itself is not the problem, instead the problem was the mistrust and conflict of interests between these groups which are driven by different and sometimes divergent needs. The existence of mining has, over time, brought about conflict and tensions in the social fabric of the local communities by polarizing it along existing fault lines of caste, religion, political affiliations etc. Consequently we revisited our approach and decided to take one ward at a time and work with each as a different stakeholder with separate interests.

Building capacity around specific goals/issues:
One of the most important components towards sustainably regenerating mining areas is that the local communities, which will be one of the main beneficiaries of this activity, have a clearly articulated vision of what sustainable regeneration means to them. We found that residents did not share a common vision for their ward, which was often rife with mistrust and suspicion. As a result there was a lack of unity and a lack of leadership, which is crucial in building partnerships. Both these factors made it necessary for us to work with the residents to first build trust among each other. Only then did it make sense that they take the next step and build trust with other stakeholders.

In such an environment, working with existing groups posed the possibility of our attempts getting hijacked by local politics. We encouraged each ward to form a citizen's association, the main focus of which would be to address issues of ward-level development. This would be done through several discussions and dissemination of our research findings. The aim of these meetings would be to develop a set of ward-level goals. With each ward's input a village level regeneration vision could be developed.

Our attempt to organize ward residents around the goal of regeneration of their wards proved to be too broad and therefore difficult to organize the community around. Hence we further fine-tuned our approach to work with existing groups around specific and tangible goals. An important lesson for us was that we could not divorce local politics from our work, but having clearly identified goals could help filter out the influence of politics on the partnership process. Thus, despite our initial decision not to work with existing groups, we identified an existing farmers' group along with a very specific goal of rebuilding agriculture to build a partnership around.

We identified a farmers' group, the Falwada Tenants Association (FTA) which was keen to rebuild agriculture on their fields that have gotten silted over the years with run-off from mine reject dumps. In dissemination meetings held we presented to the FTA the different possibilities to restart agriculture on affected fields. Information disseminated included possibilities of silt removal, dump management techniques taken up under this project, different government schemes which support rebuilding of agriculture, concepts of partnerships, sustainable regeneration etc… These meetings were also attended by representatives of the Department of Agriculture as well as those of the Minerals' Foundation[1].

[1] The Minerals Foundation is a foundation supported by the mining companies and is geared towards addressing environmental and socio-economic impacts to the local community, from mining.

In the case of Cudnem, the main problem with agricultural fields is that of reduced yields. During the monsoons the silt that is brought down through the drainage network from the mine-reject dumps enters the agricultural fields. This is the main cause of reduced yields since the silt is low in nutrients and decreases the productivity and fertility of the soil. In the past a common solution to this problem has been to offer farmers a monetary compensation towards the damages and loss suffered by them. Sometimes compensation also accounts for the cost of removing silt to continue farming. This has resulted in an unsustainable "compensation culture"[2], which comes with its attendant problems.

Over several such meetings it became evident to the farmers that if they want to restart agriculture then a holistic approach would be needed. It became clear that piece-meal efforts would be a waste of time and financial resources, as it would be tantamount to addressing the symptoms of a problem, not the root cause of it.

Discussions between farmers, government officials, and the Minerals Foundation, helped identify areas where solutions need to be found. These include desilting of fields, preventions of further run-off from reject dumps, rejuvenating the fertility of the soil and making water available for agricultural activities. There was general agreement that agriculture can be effectively restarted in this village, and that there is a role for each of the partners in meeting this common goal. In principle, the stakeholders have agreed to participate and make resources available as will be required to regenerate agriculture.

Thus addressing specific issues - regenerating agriculture - with existing groups has been more effective in addressing the issue of sustainable regeneration. Since the problem was well defined, the community already organized into a tenants' association, there existed recognized leadership within the group, a menu of possible solutions made available to trigger the imagination of the local community helped catalyze the process eliciting a positive response from the tenant's group, the government and the Minerals Foundation.

Where are we now?

Currently we are at the transition between the exploratory and partnership building phases. Based on extensive interactions with the farmers, we are in the process of assisting them draw up a plan which will detail the problems and the steps to be taken to address them. The initial draft of this document will be circulated among all the stakeholders for discussion, feedback and input. This report will help build consensus, allocate responsibilities and work out resource commitments. Based on this, we foresee a partnership-based micro-plan emerging with defined goals, objectives, roles for each stakeholders and a timeframe to achieve the goals.

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[2] Even though farmers are compensated for damage to their fields, often the amount paid does not fully account for the damage suffered by them. While it is possible to continue agriculture, it becomes increasingly costly to the farmer. With increases in local cost of labour, farmers often say they run into losses. Consequently, farms are left fallow and the compensation money acts as an incentive *not* to farm. This culture that has been built over time, is not sustinable, although it may seem like a sound choice in the short run. Inthe long run, silted fields left untended can suffer permanent damage. People become dependent on a temporary, irregular and inadequate income that is compensation. When mines close down, the compensation that they receive will stop and they will be left with unproductive and infertile land.

Major insights?

One of the most important insights which have emerged from this project was that local level institutions have a significant and crucial role to play in building and maintaining partnerships.

Why are they important?

- Helps build a common vision in the community
- In areas riddled with conflict and tensions, they help build trust through
- Local level institutions make mobilizing resources easier
- They give legitimacy to the nebulous identity often referred to as "the community"

1. Participation is more likely from community members if they are organized in "*affinity groups*" i.e. such people that have similarities or share some common reality and are therefore more likely to want to work with one another. These may be people of the same caste, religion, socio-economic group etc.
2. It is more difficult to organize people around broad goals like "sustainable regeneration" or "village development". Precise and clearly defined goals like "restarting agriculture on an fallow plot" or "building access roads to a particular village", something which is more concrete makes measuring success more tangible, which encourages all stakeholders and builds trust between and within groups. Clearly defined goals also reduce the influence of politics in partnership building.
3. Partnerships cannot be divorced from local politics yet it is important not to get caught in it. To be conscious of and recognize the influence local politics may have on partnership outcomes and work with the local politics is part of the challenge of building partnerships

What are some of the constraints faced by the different partners in building partnerships?

Community:

- Lack of leadership
- Lack of ability to develop and articulate a common vision
- Diverse interests within community
- Suspicion and mistrust within different components of community
- Absence of strong local level institutions

Industry:

- Unable to find accountable and reliable community-based groups to work with
- Limited understanding of the local community and its needs
- Stereotypical ideas about community attitudes and what it wants

Government:

- Difficult to find champions of the cause in government
- Constrained by lack of staff to carry out monitoring and enforcement

- Unavailability of appropriate data and testing laboratories to undertake necessary analysis regarding impacts of mining

NGO Working to Build Partnerships

One of the main constraints an NGO working towards building partnerships must work within is the limited timeframes. For partnerships to be successful, local level institutions play a crucial role. Where these do not exist, they need to first be created, only then can participation of the local communities in a partnership be effective. This takes a significant amount of time and is often beyond the scope of short-term projects.

Annexure 7

DEVELOPING ALTERNATIVE LIVELIHOODS: THE EVOLUTION OF SUSTAINABLE SOLUTIONS

One of the hallmarks of rural livelihoods[1] in developing countries is the diversity of income sources within households. In many rural areas a diverse livelihood portfolio might include income (both cash and kind) from both farm and non-farm activities such as crop output, livestock, farm wages, non-farm wages etc. This kind of diversity increases resilience of the household to changes in the economy and the environment through the option of substituting income from different livelihood activities and by the spreading of risk across a variety of activities.

As mining has developed and expanded in the hinterlands of Goa, the impact of mining on the land coupled with poor remediation measures has led to a decline in agricultural activities and a reduction of farm income within households. As silt from mine reject dumps has flowed into agricultural fields, traditional paddy farming and livestock rearing has come to a stop in many areas and is in decline in others. Mining and allied activities have come to play a central role in income generation to the exclusion of other activities. Over time the diversity within the livelihood portfolios of several households in the mining belt has shrunk, making the local economy less resilient to fluctuations in the international iron ore market that dictates the pace of production in Goa.

Additionally, mines are usually operational for as long as 50 – 60 years; a period long enough to create an unhealthy dependency on the industry and also long enough to ignore inevitable closure. In Goa, the dependence of the entire local economy on a single industry has left the community completely unprepared for impending closure.

Thus, one of the main thrusts of this project was to encourage alternative livelihoods to bring a moderate level of resilience back into the economy and the community. Farm and land based livelihoods were addressed through technical solutions for land remediation and non-farm livelihoods were addressed through capacity building and training programmes.

Non-Farm Based Capacity Building Programmes

While mining has created opportunities for men in the community, women's options have in fact shrunk. As agriculture has been negatively affected women working in the fields have lost a productive opportunity. Simultaneously, there are no opportunities for women in the mining sector. Research on the socio-economic conditions of the study provided several interesting insights that fed into the planning of capacity building programmes. The main activities of women in the mining areas are household tasks and child rearing, agricultural work on their own fields (where agriculture is still being practiced) and agricultural/horticultural labour work in paddy fields and cashew

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[1] Our working definition of livelihoods states that "a livelihood comprises the assets (natural physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household. (*Chambers and Conway's definition (1992) adapted by Ellis (2000)*)

plantations. Very few women work in other productive sectors.[i] While interacting with women during participatory research exercises several women expressed an interest in taking up non-farm based income generating activities such as production of household and craft items.

With this in mind we attempted to design a variety of programmes for the community with a heavy focus on women. Initially, we visited a few women in each of the study villages to ask them what kind of training programmes they would be interested in. Some women expressed an interest in training programmes for stuffed toys, artificial flowers etc. Many others didn't seem to have an idea. When offered a choice from among the programmes already listed many women asked us to sign them up for anything.

In order to maintain a level of choice and participation in the process of encouraging alternative livelihoods we decided to hold an alternative livelihoods fair where men and women were encouraged to choose what they thought was suitable to them from a variety of different skill based programmes.

In conjunction with the planning of this event we held a programme on Self Help Groups with the idea that well-functioning groups would provide encouragement from peers and most importantly, would provide a source of credit to those interested in beginning small enterprises. About 40 women from six villages attended this workshop and after the SHG programme several women called us to their villages to give them more information and help them set up their groups.

For the alternative livelihoods fair twelve trainers[2] were invited to present their crafts and provide information on the time commitment required, the availability of raw materials, possible markets and the kind of investment required to make the endeavour successful. While we had a very large turnout of women for this programme (approximately 300 women) only 5 men from the study area attended.

Most of the women who attended seemed to lack focus and clarity in terms of their choices. Almost all of them signed up for more than one training programme (despite instructions to sign up for only one programme), several women came in groups from their villages or with other SHG members and felt a level of pressure to sign up for programmes as a group rather than as individuals. Also several women were unsure of what to choose and asked TERI researchers to choose for them.

Over the following months several training programmes were held in the study area and several visits were made to the different SHGs in order gather feedback about the training programmes and to monitor progress among trainees. We found that several women who had already undergone a training programme were eager to enrol for more programmes. We also found that very few women were actually attempting to use the skills they had acquired through the training. Initial knee jerk responses to this problem included the brandishing of common stereotypes about Goans being lazy and uninterested in bettering their lives. Yet, we realised we needed to have our ear to ground more intensely in order

[2] Trainers for the following crafts attended: coconut shell crafts, seashell crafts bamboo weaving, local pottery, soap production, incense production, artificial flowers, candle making, pickle and snack preparation, bead work and jewellery, embroidery, and papier mache.

to understand the response to our programmes: We perceived this problem was happening for a variety of reasons:

- Many women were interested in the training programmes for fun because the programmes were free and conducted in the villages or as close-by as possible. (To remedy this, for programmes held later in the year we asked women to make a small contribution towards training costs but the contributions we asked for were token sums and so it didn't have the desired affect of weeding out those who were involved for fun.)
- Poverty levels in Goa are low in general (relative to poverty levels in other parts of India) and many women in the study area come from relatively well-off homes. Thus, some of the women don't perceive a need to supplement the family income. It's also possible that some women sought these training opportunities as a way to get involved in something outside the home and to make their lives more interesting or exciting rather than as an income generating activity.
- Despite having discussed the issue of mine closure and the ultimate aim of our training programmes on many occasions and through many forums, most people didn't seem to perceive mine closure as a problem in the near future. Therefore they didn't feel the need to prepare for it.
- The poorest women in the community (who we think would have responded best to our overtures) were already involved in income generating activities, working as daily wage labourers, cashew processors etc. and were unable to take time off to attend the training programmes.
- Some of the women who attended the training programmes were interested in starting or being involved in a small-scale enterprises but lacked the confidence and vision necessary to take the first steps. They also seemed unable to plan and prioritise adequately.

In order to address these issues we realised that we needed make changes in our approach. What we perceived as participatory was not nearly participatory enough. We needed to create a forum and structure within which women could visualise their own futures. Women needed to be encouraged to think about themselves, their families and their communities in the long run. Only after such an exercise would it be meaningful to ask them what they need or want in terms of training or otherwise. Additionally, we needed to find a way to include more actively the poorer groups within the community as beneficiaries of our work. It was obvious now that we needed to turn to the SHGs that had sprung up in the preceding months as a forum through which to address these issues.

At this point we organised a picnic for all the SHGs that we had been assisting to assess how their groups were functioning. We attempted to gather information ourselves and present an opportunity for groups to share with each other good practise and things that were working well within each group. At this meeting we found that several SHGs were not functioning properly. In some instances there was infighting among the members, the emphasis on democratic functioning and rotation of leaders had been forgotten. In groups that were functioning smoothly, the only activity being taken up was collection of monthly savings without any long-term vision for the group. The meetings were mundane and boring and were limited to collection of money. There were no other activities or ideas being generated through the group. In order to be able to breathe new life into these local level institutions the TERI team underwent a training programme on SHGs and local level institutions conducted by MYRADA.

Through our interaction with MYRADA we were able to understand the full potential of SHGs and the breadth of activities that can be taken up through local level institutions. Rather than focusing on income generation activities MYRADA suggests group or institutional strengthening activities where the end goal is the development of skills and capabilities within each group, including the following:

- A vision for each individual member and for the group as a whole
- Ability to make (and document) concrete and achievable plans for each year
- Ability to evaluate group activities at the end of each year based on plans developed at the beginning of the year
- Ability of each individual to evaluate their own progress as a result of being a member in the group - in terms of finances, skills and personal/character development
- Ability to mobilise support, both in cash and kind, from other institutions (NGOs, govt. etc.) to achieve group goals
- Awareness of and concern for village development and local community
- Ability to manage savings and provide credit to members in need of money

In order to develop these capabilities each SHG needs to be a well functioning unit, which in turn requires:

- Clear rules and regulations applicable to all
- Democratic functioning of groups and rotation of leaders
- Strong relationships with NGOs, government departments and other institutions
- Ability to resolve conflicts with the group
- Proper maintenance of records, of group meetings, activities, and finances

We now feel that strengthening local level institutions would be a more useful intervention and we anticipate that the development of economic activities or alternative livelihoods will flow more easily and naturally once SHGs (or other local level groups) are up and running successfully. We also realised that the community needs to be able to have their own vision and set their own targets and goals rather than have us plan for them.

We have begin the process of institutional strengthening through a variety of activities and training modules on book keeping, vision building, conducting SHG meetings etc. Importantly, we also accompanied a group of 12 women to the MYRADA training centre in Tamil Nadu where they were exposed to very successful SHGs along side three days of intensive workshops. Additionally, we have continued to provide technical training programmes to those groups that make requests.

Irrespective of the life of this project, TERI now has the responsibility to make sure that the groups we've started are able to stand on their own. Additionally, in order to make our efforts sustainable we feel the need to leave within the community the skills to train and nurture a new generation of SHGs. So how are we do this? These two issues were taken up with SHG leaders who attended the MYRADA exposure visit. After several hours of training and brainstorming we were able to identify concrete steps (or a social investment plan) towards achieving these goals:

- **Developing of community resource persons**

In order to develop a group of community resource persons we need to identify potential leaders within SHGs (most probably including the women who attended the exposure visit) and provide them with training in order to conduct modules on group strengthening. We would like to involve MYRADA in this process and follow the format of 16 modules developed by them. This would require approximately eight weeks of training broken up over 12 to 18 months, such that two or three modules can be taught to the trainees who will then try out the module with their own groups (and possibly new groups) over the period of a month. The following training session after a month would involve feedback and evaluation and then the start of new training modules. This process would go on until the trainees have internalised the ideas in all 24 modules and are able to impart them to new groups. These trainers can then be linked to the federation and can be called upon to provide training to new groups.

The cost estimates for this plan would include travel, food and stay for trainers and MYRADA's fees per trainer per day. Because the training would need to be broken up into seven or eight short programmes, the travel costs for trainers will be high. We plan work with SHGs to create a funding plan for this programme and to include a variety of potential funding sources such as the Minerals Foundation, government, large private concerns in Goa etc.

- **The formation of an SHG federation**

An SHG federation is usually composed of no less than 10 groups. They come together in order to:

- Strengthen SHGs by providing a forum for regular interaction and networking
- Disseminate information to member groups
- Undertake activities that benefit the SHGs but cannot be taken up by SHGs on their own

Ideally, the federation will be able to take over many of the roles played by the NGO, in this case TERI. The federation can take up a variety of activities including regular review of SHG functioning, auditing of SHG accounts, support and strengthening though training, ideas, exposure visits etc., and last but certainly not least the support of income generating activities and alternative livelihood etc. While the formation of a federation will not involve significant costs, it will require time and groups that are mature enough to take this next step.

Conclusion

Mining has created a fair degree of wealth within the local community, the benefits of which can be seen in homes that are fitted out with all the trappings of modern, upwardly mobile social groups including TVs, stereos, scooters etc. Yet, this veneer of wealth wears thin in the face of closing mines. In an area where traditional assets such as land and water have been degraded by mining the community has very little insurance against the fluctuations in the industry.

Thus, the process of building alternative livelihoods is clearly crucial in bringing back some resilience into the community. Yet, in order to bring about this shift, the community members have to fully understand and believe in the need for bringing back diversity of livelihoods at an individual level. In turn this requires people to have a vision for themselves, for their families and for their communities. In addition to providing technical training to support alternative livelihoods, NGOs need to paly a role in creating structures and forums through which community members can begin to deconstruct their own lives, identify their own needs and then plan accordingly for new livelihood opportunities.

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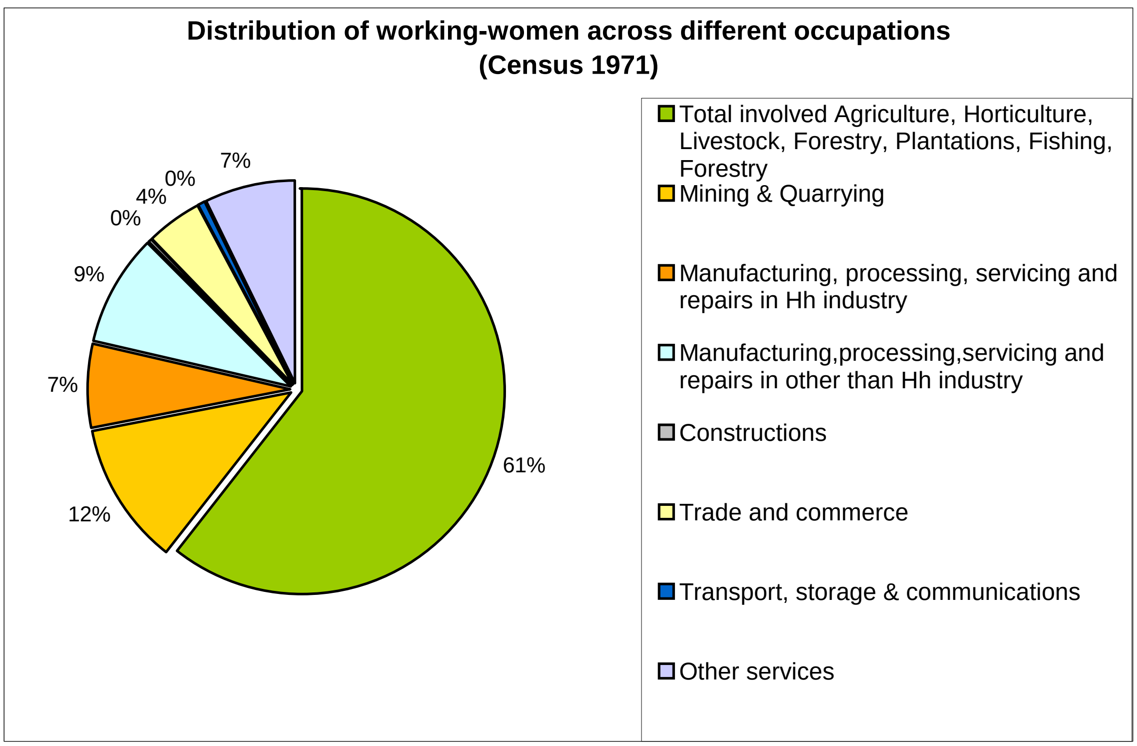
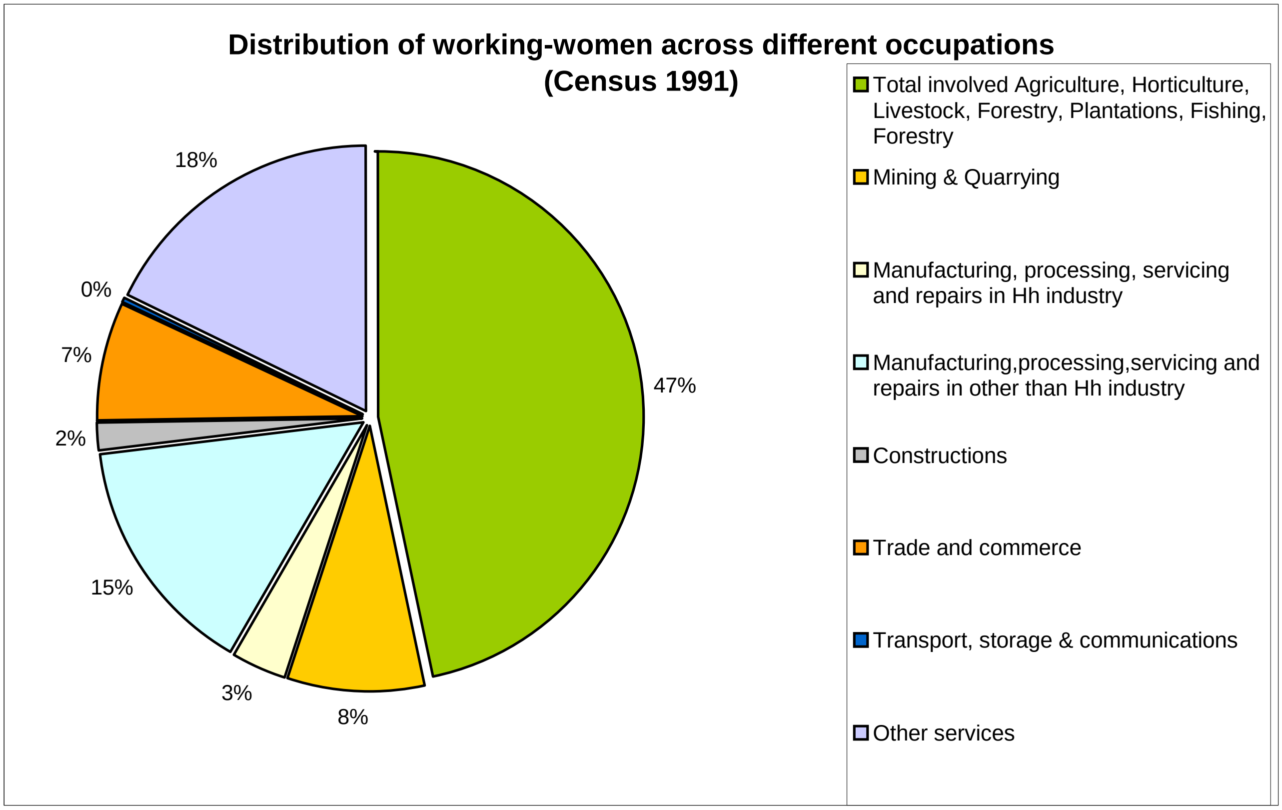
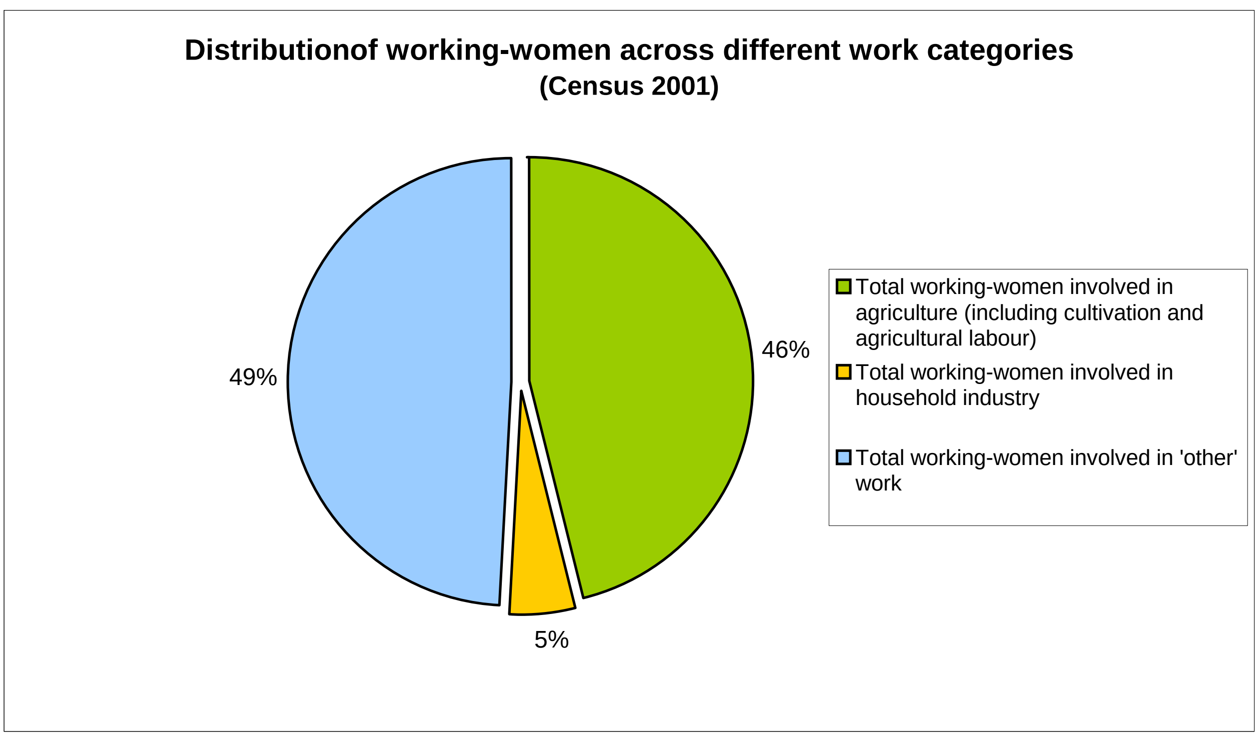


source: Census 1971



source: Census 1991



source: Census 2001

NOTE:

In the previous years census data on livelihoods was presented in a disaggregated form and it was possible to distinguish categories like plantation work, mining and quarrying, construction work etc… In 2001 census, the data presented is aggregated and the “other” category includes a vast number of heads like government servants, plantations workers, mining and quarrying, teachers, factory workers, priests etc.

Census data distinguishes between marginal and main workers (see definitions below). For the purpose of this pie-chart, this distinction has been done away with and data has been grouped by agricultural activities, household activities and ‘other work’. “Other” work seems to be the largest category as seen in the chart above, but it includes plantation workers, a land-based activity which is common amongst women in Goa. Therefore, based on this chart, we can assume that agriculture and horticulture activities still remain the largest livelihood option for women in the study area.

Definitions: (from Census metadata)

Main Workers: those who have worked for at least 6 months in the last year

Marginal workers: those who have worked for less than 6 months in the last year.

Cultivators: person cultivating land owned or held from Government or held from private persons or institutions for payment in money, kind or share. Cultivation includes effective supervision or direction in cultivation.

Agricultural Labourer: one who works on another person’s land for wages in money, kind or share

Household Industry Workers: those involved in an industry conducted by one or more members of the household at home or within the village. Household industry relates to production, processing, servicing, repairing or making and selling (but not merely selling) of goods. It does not include professions like doctors, barbers etc… or merely trade/business even if these are run from home.

Other Workers: those engaged in economic activity other than cultivation, agricultural labour or household industry. This includes all government servants, municipal employees, teachers, factory workers, plantation workers,, those engaged in commerce, business, transport, banking, mining, construction, political or social work, priests, entertainment artists etc.

Annexure-8

EXTRACTS FROM THE CONCEPT PAPER ON FEDERATIONS OF SELF HELP GROUPS PREPARED BY MYRADA

1. Reasons for promoting federations

   a) For strengthening SHGs through providing a forum for regular interaction and networking.

   b) For information dissemination to SHGs.

   c) For undertaking such activities that benefit the SHGs and communities but cannot be taken up by individual SHGs on their own.

2 Activities that a federation must undertake

   a) Regular review of the functioning of members SHGs.
   b) Strengthen SHGs through ideas, suggestions, visits, exposures, audits, training, etc
   c) Collect and disseminate relevant, useful, and interesting information to SHGs (at monthly meetings, through newsletters, etc.)
   d) Take up activities of benefit to member SHGs and communities
   e) Take up activities that strengthen the federations themselves

3 Size and constitution of a federation.

   a) Not less than 10 and not more than 20 SHGs as members.
   b) Groups that have the features of SHGs and have functioned as SHGs for atleast 6 months prior to joining the federation.
   c) SHGs will attend federation meetings for six months as observers before being granted membership..
   d) Membership in federations promoted by MYRADA will be open not only to SHGs promoted by MYRADA but other SHGs as well, on the same conditions as mentioned above.

4 Key management features of a federation

a) Training of all Self Help Group members on the basic concept and roles of federations and themselves as members

b) Federation meetings to be attended by 2 members from each SHG for a 2 year term per member, with one member of the pair retiring every alternate year. (In federations that are 4 years or older, one member per SHG to attend compulsorily; the second member is optional. This is because by then all the SHG member s have a fairly clear idea of the functioning of the federation).

c) Federation Meeting Minutes to be circulated to all members SHGs, and discussion of these Minutes to be on the agenda of each member Self help Group.

d) SHGs to be encouraged to send agenda points for discussions at federation meetings.

e) The federation should meet regularly, once a month, preferably on a fixed date and at a fixed venue.

f) Every federation must have certain basic rules and regulations for governance that are written down, known to all member SHGs and accepted by all member SHGs.

g) Rotation of cheque signatories each year.

h) Maximum opportunities for sharing responsibilities to be promoted through forming appropriate Task Forces for the various activities to be taken up.

i) The following books are to be compulsorily maintained:
   - Minutes book
   - Cash book
   - General Ledger
   - Receipt and Payment vouchers

   Maintenance of other books and documents will depend on needs and activities

j) The federation will prepare a monthly financial statement (MFS) each month

k) The work of the federation to be reviewed at each monthly meeting

l) An appraisal of performance to be done once a year, against established targets and indicators

m) An annual get-together of all members from all member SHGs where certain basic information on the performance of the federation will be compulsorily shared.

5. Means for building up the funds of federations

a) Membership / admission fees as a one-time payment from members SHGs.
b) Monthly contributions from member SHGs: a fixed amount to be collected each month.
c) Fines from member SHGs for violations of rules, etc.
d) Bank interest earned on the account of the federation.
e) Donations from any source.
f) Contributions from other institutions for programmes within the scope of the federation's objectives.
g) Service charges (when the federation's services are used for any work).
h) Income earned from any income generating programme taken up by the federation.

6 Training imparted to federations

a) **At the SHG level:** One training session per SHG for all SHG members on the concept of federations, roles of federations, and their own roles as members.
b) **At the federation level:** 3-4 training programmes attended by all federation level representatives on key topics related to the efficient functioning of federations.

MYRADA's role in the promotion and development of federations

Stage	Approximate duration	MYRADA's role
Preparatory	6 months (prior to formation of the federation)	• Discussion at SHG level on federation • Training at SHG level on concept and roles of federation sand their own roles as member • Selection of SHG representatives to the federation, and orientation to the selected representatives.
Formation	0 - 6 months	• Facilitate framing of Vision, Mission, Goals • Facilitate framing of rules and regulations, activity plans, and clarify functions, roles and responsibilities of federation and members
Stabilization	6-24 months	• Capacity building inputs • Facilitate processes on how to operationalise activity plans in accordance with Vision and Mission

Phasing out	25-36 months	• Continue to attend federation meetings periodically and facilitate federation strengthening processes • Participatory evaluation
Withdrawal	After 36 months	• Occasional "friendly" appearances at meetings and events organized by the federation

Annexure-9

Land based integrated micro-plans for regeneration of selected villages in the mining area

Soci-economic situation in Sirigao village

Sirigao is one of the smallest villages in the vicinity of mining area with a very limited land resource. There are five hamlets (Table 1) with 406 households and there are quite good number of cultivators. There are 36 families belonging to the below poverty line (BPL) and approximately around 15% of villagers are working in the mining companies.

Table 1. Socio-economic situation in Sirigao village

Number of Hamlets	**05**
Total village population	**4500**
Total number of households	**406**
Total number of BPL families	**39**
Total number of cultivators	**180**
Families involved in animal husbandry	**12**
Number of persons working in mining	**15%**
Number of dairy societies	**Nil**
Village literacy rate	**90%**
Communidars Association	**01**
Tenant Association	**01**
Credit Society	**Nil**
Primary Health Care	**Nil**
Number of High School	**01**
Number of Balawadi's	**02**
Number of Primary schools	**01**

Source: Sirigao Village Panchayat, Feb 2004

Table 2. Details on land resources of Sirigao

Total area of the village	287 Ha
Total forest area	Nil
Total irrigated area	20 Ha
Total un-irrigated area	30 Ha
Culturable waste land	16 Ha
Area not available for cultivation	140 Ha
Total area under mine pits	40 Ha
Total area under mine dumps	30 Ha
Total area under fallow land	09 Ha

Source- Village Panchayat, Feb 2004, AQEM, 1997 & field observations

Water resources at Sirigao

Water resources form an integral part of land-based activity/enterprenships. A number of ponds and common drinking water wells exist in sirigoa village (Table 3). But some of these ponds are silted by mining dumps and well water is not being used for domestic purposes. There are three drainage lines identified in the village and among these one drain line is completely silted.

Table 3.Identified water resources at Sirigoa

Number of ponds	06
Total number of common wells	05
Number of drainages/streams	03
Number of Manas	02
Number of Bandhars	Nil

Source – Field observations, Feb 2004

Major Problems related to Land and water resources are as follows:

- Limited availability of land resources (in terms of Barren, pasture land etc)
- Erosion from dumps leading to Siltation of agricultural lands
- Barren and partially rehabilitated dumps
- Abandoned pits
- Less output from the paddy cultivation
- Back water inundation in the agricultural fields
- Siltation of streams, ponds - thereby reduced water storage capacity
- Decreased groundwater levels
- Siltation of Manas
- Decrease in the available area of Manas
- Reduced fish production
- Unhealthy growth of fish due to turbid water during monsoon

Rebuilding approaches for Sirigao Village

1. Rebuilding of agriculture activity can be taken up

   - By disilting of affected fields
   - Fencing of fields to stop further siltation

- Construction of stonewalls and filter trenches at the base of dumps to arrest further flow of silt.
- Supply of hybrid paddy seeds and fertilizer to the farmers
- Funding can be sought from mining company, department of agriculture and contribution from beneficiaries.

Table 4. Identified resources for integrated development

Type of resource	Unit	Number of beneficiaries
Silted agricultural land	25 Ha	60
Number of silted ponds	02	16
Number of drainage lines	01	10
Number of silted Manas	02	20
Barren land for development of Nursery	10000 sq.mts	06
Fallow land for fodder grass	1.5 Ha	12
Fallow land for group olericulture	1.0 Ha	08
Fallow land for development of floriculture	1.0 Ha	10
Barren dumps	30 Ha	Village community
Area under mine pits	40 Ha	Village community

2. Disiltation activity shall be taken up for silted ponds, which form an important source for paddy cultivation in Sirigao village.

3. Development of a group nursery in the identified barren area shall be taken up and community may approach Department of agriculture for possible financial assistance.

4. Existing barren dumps forms an important land resource for the entire community of Sirigao village. These dumps shall be rehabilitated with advanced soil and water conservation measures and by using economically viable species.

5. Development of olericulture (species such as Chilli, Brinjal, Reddish and Onion) plot in the identified fallow land would be more feasible, as villagers have limited land area for olericulture cultivation and this can be a very good activity for Sirigao village.

6. Development of group floriculture (species such as Gladiolus, Rose, Marigold, and Crossandra) would be an important economic source of identified community and there is a demand in the local market.

Integrated micro-plans for Cudnem village

Cudnem is another village in the mining area of North Goa. It is noticed that the eastern part of the village is under extensive mining activity where as western part of the village is relatively free from the mining activity. Following are the identified main hamlets in the vicinity of mining activity;

- Chickni
- Falwada (Upper and Lower)
- Karmale
- Gurmale
- Pethwada

Socio-economic situation in Cudnem village

There are seven hamlets (Table 5) in the cudnem village with 734 households and the total population of the village is 8000. There are good number of cultivators and 30% of people are working in the mining related activities. The literacy rate of the village is around 75 % and there are two functioning tenant associations and total numbers of below poverty line families (BPL) are 131.

Table 5. Socio-economic situation in the cudnem village

Number of Hamlets	**07**
Total village population	**8000**
Total number of households	**734**
Total number of BPL families	**131**
Total number of cultivators	**150**
Families involved in animal husbandry	**10%**
Number of persons working in mining	**30%**
Number of dairy societies	**01**
Village literacy rate	**75%**
Tenant Association	**02**
Credit Society	**01**
Primary Health Care	**Nil**
Number of High School	**01**
Number of Balawadi's	**05**
Number of Primary schools	**03**
Cashew factories	**02**

Source - Cudnem Village panchayt Feb 2004)

Land resources of Cudnem Village

Cudnem is one of the largest villages in the mining area of North Goa with a total geographical area of 991 ha (Table 6). Approximately about 131 ha of area (mostly in the western part of the village) are under paddy cultivation.

Table 6. Details on land resources of Sirigao

Total area of the village	991 Ha
Total forest area	Nil
Total area under paddy	131 Ha
Total area under mine pit	142 ha
Culturable waste land	163 Ha
Area not available for cultivation	445 Ha
Total area under mine dumps	110 Ha

Source- Village Panchayat, Feb 2004, AQEM, 1997 & field observations

Problems related to land Resources

Following are the some of specific problems related to land resources of Cudnem village;

•Erosion from dumps leading to siltation of agricultural lands & streams

•Barren & partially rehabilitated dumps

•Abandoned pits

• Less out put from the paddy cultivation

•Conversion of agricultural land for construction

•Conversion of available area for mining and related activities

•Reduction of yield in plantation crops due to dust deposition on the canopy

•Conversion of unclassified forest into barren patches due to felling of trees

Rebuilding approaches for Cudnem village

Following are the some of suggested rebuilding approaches for integrated development.

1. At Karmale and Gurmale, the identified pasture land shall be utilized for the development of horti-pasture and silvi-pasture along with crescent shape trenches.

Table 7. Hamlet wise identified land resources for integrated development

Type of resource	Unit Area	Number of beneficiaries
Karmale & Gurmale		
▪ Identified pasture land	4 Ha	20
▪ Identified barren hillock	2 Ha	20
▪ Identified barren dump	6 Ha	Karmale & Gurmale
▪ Identified Common drinking Water well for renovation	01	Karmale & Gurmale
▪ Identified drainages for treatment	01	Karmale & Gurmale
▪ Identified silted paddy field	02	5
Falwada		
▪ Silted agricultural land	19 Ha	35
▪ Fallow land	15 Ha	38
▪ Pasture land	05 Ha	12
▪ Barren land	05 Ha	10
▪ Land under vegetable cultivation	0.5 Ha	05
Chickni		
▪ Silted agricultural land	07 Ha	10
▪ Cultivable agricultural land	08 Ha	15
▪ Fallow land	05 Ha	10
▪ Pasture land	06 Ha	12

2. Identified barren dumps shall be rehabilitated with advanced soil and water conservation measures and also there is a need to use economically viable species.

3. Disilting activity of silted agricultural lands shall be taken up in all the hamlets along with fencing, construction of walls, providing hybrid seeds as fertilizer to improve the yield.

4. In the areas of fallow land, the coconut plantation with intercrop banana can be grown. Some parts of fallow land also can be utilized for development of floriculture plot as well as vegetable plot.
5. Identified pasture lands shall be used for growing fodder grass, since some of the families have animal husbandry, which can be a very good source.

Mulgao Village

Dempo mine is the only working mine in Mulgao village. Affected wadas in the vicinity of mining are Shirodwada, Mans wada and Gaonkar wada.

Mulgao is one of the villages having more land area with seven wadas (Table 1) and the total population is around 3327 with 636 numbers of households. There are quite good number of cultivators and about 125 persons are working in the mining company.

Table 1. Socio-economic situation in Mulgao village

Number of hamlets	07
Total population	3327
Total number of households	636
Number of cultivators	300
Number of Tenant association	01(Khard Khazan Savad Khazan sethki committee)
Families involved in animal husbandry	25
Number of persons working in mining	125
Number of BPL families	100
Literacy rate	60 %
Number of dairy societies	Nil
Number of credit societies	Nil
Number of high school	01
Number of primary school	04
Number of Balwadi’s	02
Number of communidar association	Nil

(Source - Mulgao Village panchayt April 2004)

Common problems identified in the village

Table 2. Details on the land resources of Mulgao village

Total area of the village	758.39 Ha
Total area not available for cultivation	286.89 Ha
Culturable waste land	69.72 Ha
Forest area	Nil
Total un-irrigated area	325.77 Ha
Total irrigated area	76.01 Ha
Area under mine pits	65 Ha
Area under mine dumps	35 Ha
Area under fallow	15 Ha

(*Source- Village Panchayat, April 2004, AQEM, Field observations*)

Problems related to land resources

Following are the some of specific problems related to land resources in the Mulgao village.

- Erosion from dumps in to nearby agricultural fields and water bodies leading to siltation.
- Partially rehabilitated dumps
- Backwater inundation in to the agricultural fields
- Problem of land ownership

Water resources in the Mulgao village

There are five ponds and six common drinking water wells (Table 3). There are four major drainage lines and existing bahndharas are two. Most of these identified ponds; major drainage courses and bandharas are partially silted.

Table 3. Identified water resources in the Mulgao village

Number of ponds	05
Common wells	06
Number of major drainages	04
Number of Bandharas	02
Number of Manas	01

Source: Field observations, April 2004

Problems related to water resources

- Siltation of streams and ponds
- Decrease in the groundwater levels

Table 4. Identified resources for integrated development in the Mulgao village

Type of Resource	Unit	Expected number of beneficiaries
Silted agricultural lands	8 ha	20 families
Silted ponds	02	30 families
Silted drainages	04	10 families
Identified barren patch	03 ha	08 families
Fallow land	06 ha	10 families

***** *Most of the dumps identified in the area are presently active and plantation cannot be taken up at the moment.*

Rebuilding approaches for Mulgao village

Following are the some of rebuilding approaches for Mulgao village by looking into the identified resources at stress in the vicinity of mining.

- Desiltation of agricultural fields and ponds can be taken up to help the communities to involve them in the agricultural activity with necessary support.
- Along the course of silted drainages in the village, loose boulder structures would be appropriate to arrest further siltation and to retain base flow.
- In the identified barren path, plantation of chikku and jackfruit can be taken up.
- Identified fallow land can be utilized for growing vegetables and floriculture.
- Ongoing dumping activity in the area requires to follow the scientific methods to avoid future problems, which can seriously affect the surrounding agricultural fields.
- Sowing of grass species would be feasible on the active dumps, which can be utilized as fodder for the animal husbandry, and beside this the main objective is to stabilize the dumps as well as to arrest the further siltation.

Pissurlem Village

The main working mining companies in this village are DMC and SESA Goa limited. Main wada's affected are Gaonkar wada, Dhat wada and Bhand wada.

In Pissurlem village there are six wadas and total population of the village is around 2200 (Table 5). There are 421 households and total numbers of cultivators (including male and female) in the village are 52. There is a presence to two tenant associations and quite good number of persons working in the mining companies. Families belonging to below poverty line are 32 and families involved in animal husbandry are 35 and there are two milk co-operative societies in the village.

Table 5. Socio-economic situation in Pissurlem village

Number of hamlets	06
Total population	2200
Total number of households	421
Number of cultivators	52
Number of Tenant association	02
Families involved in animal husbandry	35
Number of persons working in mining	289
Number of BPL families	32
Number of milk co-operative societies	02
Number of credit societies	Nil
Number of high school	01
Number of primary school	08
Number of Balwadi's	03
Number of communidar association	Nil

(Source - Pissurlem Village panchayt April, 2004)

Common problems in the village

- Siltation of agricultural fields
- Feel of insecurity due to closure of mines
- Unemployment
- Water scarcity
- Dust pollution

Land resources of Pissurlem village

The total area of the pissurlem village 833.85 hectares (Table 6) and half of this area is not available for cultivation, which is approximately around 450 hectares. Culturable wasteland is around 237 hectares and there is no forest area. The total area under the mine pits approximately 135 hectares and area under dump ranges approximately from 100 to 110 hectares.

Table 6. Details on the land resources of Pissurlem village

Total area of the village	833.85 Ha
Total area not available for cultivation	449.16 Ha
Culturable waste land	237.87 ha
Forest area	Nil
Total un-irrigated area	112.3 Ha
Total irrigated area	34.49 Ha
Area under mine pits	135 ha
Area under mine dumps	100 ha
Area under fallow	10 ha

(***Source- Village Panchayat, April 2004, AQEM, Field observations***)

Problems related to land resources

- Siltation of fields derived from neighboring dumps
- Stopped cultivation and kept fallow during kharif season
- Low output in the production than the investment
- No interest in the community towards development land resources.

Water resources at Pissurlem village

There are very few water resources available in the pissurlem village. It observed that there are eight number common drinking water wells without drop of water (Table 7). It is also observed that there is a drastic fall in the local groundwater level. Besides this, there are three silted drainage lines, which carry lots of siltation to the neighboring agricultural fields during monsoon.

Table 7. Identified water resources in the Pissurlem village

Number of ponds	01
Common wells	08 (almost dried)
Number of major drainages	03
Number of Bandharas	Nil
Number of Manas	Nil

Problems related to water resources

- Silted pond
- Silted streams
- Streams carrying silt to agricultural fields during monsoon
- Drop in the local groundwater table

Table 8. Identified resources for integrated development of Pissurlem village

Resource	Unit	Expected number of beneficiaries
Silted agricultural lands	27 ha	60 families
Silted ponds	01	35 families (Bhand &Gaonkar wada)
Silted drainages	03	30 families
Pasture land	3 ha	10 families
Fallow land	35 ha	50 families
Identified barren dump	25 ha	Communities of pissurlem
Partially rehabilitated dump	35 ha	Communities of pissurlem
Gullies in the dumps	20 ha	Communities of pissurlem
Identified coconut orchid	03 ha	Communities of pissurlem

Rebuilding approaches for Pissurlem village

- Desiltation of agriculture fields, ponds and streams/drainage lines can be taken up.
- There is a required need to treat the gullies formed in the old dumps (along the gullies loose boulder structures would be feasible).
- Rehabilitation of dumps is required with economically viable species along with advanced soil and water conservation measures.
- Development of plantation plot would be taken up in the identified pastureland.
- Inter crop can be grown in the identified coconut orchid.
- Cowpea and groundnut can be grown as Rabi crop in the paddy fields.

Sonshi Village

The working mining companies in the village are DMC, Keni brothers and SESA Goa. There are only three wadas in the village (Sonus wada, Ovaliem wada and Chirewal wada). The total population of the village 402 with approximately 120 households (Table 9). There is very small number of cultivators and 16 families are involved in the activity of animal husbandry. Around 70 persons are working in the mining companies and families below poverty line are 20.

Table 9. Socio-economic situation in Sonshi village

Number of hamlets	03
Total population	402
Total number of households	120
Number of cultivators	05
Number of Tenant association	Nil
Families involved in animal husbandry	16
Number of persons working in mining	70

Number of BPL families	20
Literacy rate	30%
Number of dairy societies	Nil
Number of credit societies	Nil
Number of high school	Nil
Number of primary school	02
Number of Balwadi's	01
Number of communidar association	Nil

(Source - Sonshi Village panchayt April 2004)

Common problems noticed in the village

- Siltation
- Dust and air pollution
- No unity among communities
- No scope for agriculture
- Heavy traffic created vibration and noise pollution
- Insecurity among the communities due to expected close of working mines

Land resources of Sonshi village

Sonshi is another small village in the mining area of north Goa with total geographical area of 474 hectares. Most of the land area has been converted into either mine pit or for the dumping mine rejects. Approximately around 100 hectares of area is under mine pits as well as approximately around 133 hectares of area is under partially rehabilitated dumps.

Table 10. Details on the land resources of Sonshi village

Total area of the village	474.12 Ha
Total area not available for cultivation	107.90 Ha
Culturable waste land	0.05 Ha
Forest area	Nil

Total un-irrigated area	303.97 Ha
Total irrigated area	7.23 Ha
Area under mine pits	100 ha
Area under mine dumps	133 ha
Area under fallow	10 ha

(***Source- Village Panchayat, April 2004, AQEM, Field observations***)

Problems related to land resources

- Silted agricultural fields
- Barren dumps
- Most of the land converted to mining
- Limited agricultural fields
- Fewer yields from the plantation crop due to dust deposition.

Table 11. Water resources in the Sonshi village

Number of ponds	Nil
Common wells	04
Number of major drainages	02
Number of Bandharas	Nil
Number of Manas	Nil

Problems related water resources

- Silted drainages
- Dried common wells
- Decrease in the groundwater table
- Limited water resources

Table 12. Identified resources for integrated development at Sonshi village

Resource	Unit	Expected number of beneficiaries
Silted agricultural lands	5 ha	10 families
Thick layer dust deposition on the agricultural land	03 ha	08 families
Silted drainages	02	10 families
Barren patch	04 ha	10 families
Fallow land	03 ha	06 families
Identified barren dump	50 ha	Community of Sonshi
Partially rehabilitated dump	80 ha	Community of Sonshi

** It is very important to notice that there are more number of mining pits (abandoned and working) than other villages of mining activity.*

Rebuilding approaches for Sonshi Village

- Desiltation of agricultural fields and removal of dust can be taken up.
- Rehabilitation of dumps with appropriate species and adoption of scientific measures of soil and water conservation would be feasible.
- Identified fallow land can be utilized for the cultivation of vegetables, and growing fodder grass can be useful for animal husbandry.
- Identified barren patch would be useful for horti-pasture and horti-silvi pasture activities.
- In general, there is very less scope of agricultural activity in the village. Most of the area is converted to the mine related activities. This village is very severely affected by mining activities.

Annexure 10

Capacity Building Programmes

TECHNICAL TRAINING and AWARENESS PROGRAMMES

AGRICULTURE RELATED

Integrated Watershed Management
Date: 12th-15th May, 2003
Venue: Pissurlem School Hall, Pissurlem Village, Goa
No. of Participants: 40

Rebuilding Agriculture I
Date: 19th and 20th May, 2003
Venue: Bicholim Panchayat Hall, Bicholim
No. of participants: 35

Nursery Management
Date: 20th July 2004
Venue: Ella Farm Old Goa
No of Participants: 20

Vermicomposting
Date: 21st July 2004
Venue: Mangao, Maharashtra
No of Participants: 20

Soil and Water Conservation
Date: 30th September 2004
Venue: ICAR complex, Old Goa
No of Participants: 20

Rebuilding Agriculture Workshop II
Date: 4th March 2005
Venue: Zantye Hall, Bicholim
No. of participants:

CRAFTS AND HOUSEHOLD ITEMS

Alternative Livelihoods Fair
Date: October 9th, 2003
Venue: Dada Borkar Hall, Sanquelim, Satteri
No. of participants: 325

Incense making workshops

Date: 7th and 8th November 2003
Venue: Soliyem, Sonus
No. of participants: 21

Date: 22nd January 2004
Venue: Karmale wada, Cudnem
No. of participants: 34

Date: 23rd January 2004
Venue: Panchayat Hall, Karapur
No. of participants: 17

Date: 24th January, 2004
Venue: Ghadiwada, Maulinge
No. of participants: 26

Coconutshell Crafts workshop
Dates: 2nd-11th February 2004 (half day)
Soliyem wada, Sonus
No. of participants: 31

Fruit Preservation- exposure visit cum training
28th June 2004
Venue: Savoi-Vere, Ponda
No. of participants: 20

Candle Making
Dates: 10th – 12th July 2004 (full day)
Venue: Kelbaiwada, Mayem
No. of participants: 10

Seashell Crafts workshop
18th –24th December, 2004 (full-day)
Venue- Public Library, Gaonkarwada Mayem
No. of participants: 16

Cooking/Catering Programmes

Date: 19-20th Nov. 2004
Venue: Poira, Mayem
No. of Participants: 33

Date: 4 –11 Dec. 2004 (half day)
Venue: Sirigao
No. of participants: 16

Date: 5- 14th Jan. 2005 (half day)
Venue: Soliyem
No. of participants: 17

Date: 30th Jan. – 5th Feb. 2005 (half day)
Venue: Dhat wada, Pissurlem
No. of participants: 17

INSTITUTIONAL STRENGTHENING PROGRAMMES AND WORKSHOPS

Introduction to Self-help Groups
Date: 7th and 8th May 2003
Venue: High school hall, Pissurlem
No. of participants:

SHG Picnic
Date: 10th March 2004
Venue: Mayem Lake
No. of participants:

MYRADA Institutional Strengthening workshop (for staff)
Date: 2nd –7th October 2004
Venue: Myrada Germalam Training Centre
Erode District, Tamil Nadu
No. of participants: 5

"How to Conduct a Meeting" workshop

Date: 21st December 2004
Venue: Bandh wada, Pissurlem
No. of participants: 35

Date: 17th January, 2005
Venue: Chikhne, Cudnem
No of Participants: 8

MYRADA exposure visit
Date: 21st- 23rd Feb. 2005
Venue: MYRADA Germalam Training Centre
Erode District, TN
No of Participants: 17

Book keeping workshop
Date: 8th – 12th March 2005
Venue: Zantye Hall, Bicholim, Goa
No of Participants: 12

Vision Building workshop
Date: 28th Mar. 2005
Venue: Soliyem, Sonus

Sustainable Regeneration of Mining Areas through Tri-sector Partnerships
Final Dissemination/Consultative Workshop
25th May 2005
Zantye Hall, Bicholim
No of Participants: 11

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Annexure-11

List of research publications during 2004-2005

A. Publications in <u>Refereed Journals</u>

1. *Chachadi A.G, Choudri B.S. and Noronha* L, ***2004*** - Estimation of Surface Run-off and Groundwater Recharge Using Daily Sequential Water Balance Model the 'BALSEQ' – Application in Goa Mining Area" -*Journal of Indian Association of Hydrology (IAH), Volume.27/1-2, pp. 1-15.*

2. *Chachadi A.G. Choudri B.S.* ***2004*** **–** Well hydrographs as tools for impact assessment of open cast mining on groundwater regime in Goa **(Journal of Applied Hydrology, Association of Hydrologists)**

<u>B. Technology Development and Dissemination</u>

1. Pilot Scale trails of plantation and Soil-water conservation measures on representative mine dumps – a case study from North Goa **(TERI booklet, 2004)**

2. A methodology for evaluation of mine pit rehabilitation using multiple parameter approach **(TERI booklet, 2004)**

<u>C. Chapters in Books</u>

1. *Choudri B.S.* and *Chachadi A.G.* **2005** – Status of Groundwater Recharges and availability in the Mining Watersheds of North Goa **(TERI Publication in Press on "Global Environmental Change")**

<u>D. Research papers in Press/ Communicated</u>

1. *Choudri B.S.* **2005 -** Study on groundwater recharge and status on water use in Dicholi Watershed – An approach for integrated watershed development **(Journal – Indian Association of Soil and Water Conservation)**

2. *Sharma J.V., Choudri B.S. and Sridharan P.V.* ***2004*** **-** Pilot scale trials of plantation and soil–water conservation measures on representative mine degraded land – A case study from Goa **(Journal -** ***Indian Forester, Dehra Dun)***

3. *Chachadi A.G., Choudri B.S and Noronha L,* ***2004*** **–** Mine Pit Rehabilitation Index (MPR-INDEX) – An Indicator based decision making Tool **(International** ***Journal of Surface Mining, Reclamation and Environment, Canada)***

4. *Choudri B.S.* and *Chachadi A.G.* **2005** – Status of Groundwater Recharges and availability in the Mining Watersheds of North Goa, Goa **(*Journal - Indian Association of Hydrology (IAH)), Roorkee)***

Annexure - 12

Schemes available for Resource Development at Village level

Department of Agriculture & Horticulture Board

•Assistance for high yielding certified seeds (50% subsidy)

•Fencing to agriculture field (50 % subsidy)

•Plant protection (50 to 75 % subsidy on bio-control measures)

•Disilting of ponds (100 %)

•Cultivation of banana (50% subsidy on cost of input)

•Supply of vegetable seeds (50% subsidy)

•Development of commercial horticulture (25 % of project cost)

•Repair of embankments (50 % subsidy)

•Assistance for coconut cultivation (Rs. 8000 per Ha)

•Assistance for cashew cultivation (Rs. 6300 per Ha)

•Assistance for minor fruits crops (Rs. 7000 per Ha)

•Assistance for major fruit crops (Rs. 10,000 per Ha)

•Assistance for floriculture (Rs. 15000 to Rs. 20,000 per 0.2 Ha)

• Cultivation of spices (25 % to 50 % subsidy on planting material)

•NWDPRA - Soil & water conservation (90 to 95 % subsidy)

•Farm production (50% subsidy)

•Micro-irrigation (35 % subsidy)

•Assistance for nursery development (50 % subsidy on shade nets)

•Assistance for Wasteland development

Department of Forestry

•Assistance for developing a social Forestry

•Assistance for development of people's nursery

•Assistance for development of firewood

•Assistance for mangroove plantation

•Assistance for growing biofuel species

•Assistance for bamboo plantation

Department of Animal Husbandry

•Subsidy for buying mulch animal (25 % subsidy)

•Kamadenu scheme (100% loan and 40% subsidy)

•Cultivation of fodder grass (Rs. 6000 to Rs. 10,000 for 3 Yrs)

•*Department of Fishiries*

•*Brackish water fish farmer's development agency- gives 30% subsidy per hector on fish farming.*

•Purchase of fishing net for traditional fisherman

•Subsidy on purchase of fishing requisites

Department of rural development

•Digging of open well & purchase of water pump (Rs.25000)

•Support for dairy farming

•Support for Fisheries

•Assistance to marginal farmer (33.5 %)

•Assistance to agricultural Labourer (33.5 %)

•Assistance for land development & social forestry

Department of Irrigation

•Assistance to lift irrigation

•Assistance to construction of Baandhars & wells

•Assistance to anti-sea erosion control

•Assistance to flood control

•Assistance for improvement of drainage systems

•Assistance for disilting of tanks/wells

Department of Agriculture

Name of activities	Assistance
Development of Floriculture	▪ Input assistance of Rs. 20,000 is provided to 0.2 Ha of area for beneficiaries take up cultivation ▪ Input assistance of Rs. 15000 is provided for beneficiaries for taking up cultivation of grafted/ hybrid plants on commercial scale ▪ Input assistance of Rs. 4000 is provided for beneficiaries taking up floriculture of seed propagated plants on commercial scale. ▪ Training on floriculture ▪ Assistance for flower show

Schemes under NWDPRA

Name of Activities	Assistance

All soil/water conservation and water harvesting works on private land	90% assistance and requires 10% contribution from Beneficiaries
All soil/water conservation works and drainage line treatments benefiting community	95% assistance and requires 5% contribution from Beneficiaries
Supply of planting material	50% assistance and requires 50% from the beneficiaries
Testing and demonstrations on new technologies on private field	100% assistance provided to the beneficiaries
Adoption of proven technology	100% loan provided from the project fund